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The present volume contains the contributions from the Woods Hole Oceanographic Institution which appeared during 1936 in publications other than *Papers in Physical Oceanography and Meteorology;* also the Annual Report of the Director.

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THE WOODS HOLE OCEANOGRAPHIC INSTITUTION
Report for the year 1935

Contribution No. 65

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OCCURRENCE AND DISTRIBUTION OF THE MARINE PROTOZOAN SPECIES IN THE WOODS HOLE AREA[1]

JAMES B. LACKEY

(*From the Woods Hole Oceanographic Institution*[2])

Investigations of the marine species of Protozoa and of their regional, seasonal, and vertical distribution and numbers are few although much descriptive attention has been given to certain groups. Such are the studies of the Radiolaria collected by the Challenger and other expeditions; the work of Brady (1884) and Rhumbler (1900) on the Foraminifera; or the papers of Schaefer (1923, 1924, 1926) on the marine amœbas. The marine Mastigophora have received scant attention as a whole although Lohmann (1902) and Schiller (1926) have published important papers. The Dinoflagellata, however, have been extensively investigated, notably by such workers as Kofoid and Swezy (1921), and Lebour (1925). There is even less general work on the marine Ciliata, although the Tintinnoidea have been extensively studied by some workers, notably Jorgensen (1927), and there are descriptive papers by Fauré-Frémiet (1924) and Kahl (1928). The " Nordische Plankton " presents a survey of the marine Protozoa, and the chapter on pelagic plant life by Gran (1912) in " The Depths of the Ocean " gives a generalization of what is known with regard to the pigment-bearing forms. How little we actually know of the occurrence and functions of the Protozoa in the seas is indicated by the fact that in the book " The Marine Plankton," (Johnstone, Scott and Chadwick, 1924) the Protozoa are not considered except for the " vegetable plankton," i.e., peridinians, whereas it has been definitely shown that a considerable part of the plankton both by numbers and volume may consist of Protozoa.

They are probably more numerous and more important than is generally realized. Gran (1912) recorded more than " 200,000 calcareous flagellates per liter . . . just outside the European coast bank " and Allen (1919) reported 14,450 per liter of sea water. He used the hand centrifuge to concentrate the organisms but was dissatisfied with the method, so by diluting his sea water into culture media and counting his cultured organisms, he estimated that the population of the sample was at least 464,000 per liter, and says "The real number must be greater than this." Only about two-fifths (178,000) of this population were Protozoa, but any such number must exert a considerable influence on the other organisms in the same water. On the other hand, as Allen pointed out, his estimated number of Protozoa may have been too small since his media were not particularly favorable for the growth of these animals.

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[1] Journal Series Paper, New Jersey Agricultural Experiment Station, Department of Water and Sewage Research.

[2] Contribution No. 65.

If the marine Protozoa are as abundant as these two instances indicate, they certainly merit more careful investigation as plankton components. Clemens' (1933) North American Pacific Coast check list includes 300 species; Smith (1904) noted 54 species from the Gulf of Mexico; Calkins (1902) studied 74 species from the Woods Hole area. Gran (1933) gave the numbers present and distribution of 4 species of flagellates, 22 of dinoflagellates, and 9 of ciliates from the Gulf of Maine; Cushman (1908) found 28 species of Foraminifera in the Woods Hole region; Martin (1929) listed 35 species of dinoflagellates from the New Jersey coast. Very little seasonal distribution has been studied in North American waters, but this phase has been investigated in the North Sea and the English Channel by Cleve (1899, 1900), Gran (1912), Herdman and Scott (1908–15), Lebour (1917) and others. From June first through early September, 1934, I studied the occurrence and distribution of the Protozoa of the Woods Hole Area.

Procedure

Studies were principally confined to those organisms occurring in water taken at the wharf of the Oceanographic Institution; the water is so turbulent there because of the strong tidal current sweeping through the Hole between Buzzards Bay and Vineyard Sound that this point samples both and there is hardly a difference in the vertical distribution of the plankton. Samples were also taken from the Bay and the Sound at various times with occasional samples from more distant points. Swimming and floating forms were secured by filtering or centrifuging samples of water varying from 120 cc. to 5 liters. A plankton net was often used to determine what larger species were present but was useless for counting purposes although relative numbers could be determined by examining the catch. Bottom-dwelling forms were secured by suspending traps from the float and by core sampling devices; later in the summer a small core bottom sampler was constructed.

Table I

The genera and species of marine Protozoa identified from the Woods Hole area

	Floating	Attached or in Debris	From Bottom Samples
Class			
Sarcodina			
Subclass			
Rhizopoda			
Order			
Proteomyxa			
Labyrinthula sp.		X	
Vampyrella sp.	X	X	
Nuclearia simplex		X	
Arachnula impatiens	X	X	
Proteomyxa sp.		X	X
Biomyxa vagans		X	X
Foraminifera			
Pulvinulina menardii		X	X
Pulvinulina lateralis		X	X
Rotalia sp.		X	X
Spiroloculina sp.		X	X
Biloculina elongata		X	X
Polystomella striatopunctata		X	X
Miliolina seminulum		X	X
Miliolina circularis		X	X
Amoebaea			
Pelomyxa sp.			X
Vahlkampfia limax	X	X	X
Vahlkampfia albida	X	X	X
Amœba spp.	X	X	X
Hartmanella hyalina	X	X	X
Testacea			
Allogromia lagenoides		X	
Allogromia ovalis		X	X
Shepheardiella sp.		X	
Amphitrema sp.		X	
Pseudodifflugia gracilis		X	
Actinopoda			
Heliozoa			
Oxnerella maritima		X	
Eleorhanis sp.	X	X	
Raphidiophrys sp.		X	
Wagnerella borealis		X	
Pinnacocystis sp.	X	X	
Actinophrys sol	X	X	
Actinophrys sp.	X	X	
Clathrulina elegans	X		

	Floating	Attached or in Debris	From Bottom Samples
Class			
Mastigophora			
Subclass			
Phytomastigoda			
Order			
Chrysomonadida			
Chrysapsis agilis	X	X	
Chromulina minor	X		
Chromulina mikroplankton	X		
Chromulina sp.	X		
Hymenomonas roseola	X		
Erythrymonas haltericola	X		
Kephyrion ovum	X	X	X
Ochromonas variabilis	X		
Ochromonas ludibunda	X		
Pontosphaera huxleyi	X		
Syracosphæra sp.	X		
Calyptrosphæra oblonga	X		
Mesocena sp.	X		
Dictyocha fibula	X		
Dictyocha staurodon	X		
Distephanus speculum	X		
Distephanus crux	X		
Distephanus crucis	X		
Cryptomonadida			
Cryptomonas erosa	X		
Chilomonas paramecium	X	X	
Chlorachne desmorpha	X	X	
Rhodomonas baltica	X		
Rhodomonas pelagica	X		
Rhodomonas sp.	X		
Nephroselmis marina		X	
Dinoflagellida			
Exuviælla lima	X		
Exuviælla compressa	X		
Prorocentrum dentatum	X		

TABLE I (*Continued*)

	Floating	Attached or in Debris	From Bottom Samples
CLASS			
Mastigophora (cont.)			
SUBCLASS			
Phytomastigoda (cont.)			
ORDER			
Dinoflagellida (cont.)			
Prorocentrum scutellum	X		
Prorocentrum triangulatum	X		
Prorocentrum micans	X		
Peridinium depressum	X		
Peridinium roseum	X		
Peridinium achromaticum	X		
Peridinium trochoideum	X		
Peridinium mite	X		
Peridinium pallidum	X		
Peridinium inermes	X		
Peridiniopsis asymmetricum	X		
Ceratium tripos	X		
Ceratium tripos var. *atlantica*	X		
Ceratium tripos var. *atlantica* forma *baltica*	X		
Ceratium tripos var. *atlantica* forma *neglecta*	X		
Ceratium tripos var. *subsalsa*	X		
Gonyaulax triacantha	X		
Gonyaulax scrippsiæ	X		
Gonyaulax spinifera	X		
Gonyaulax digitale	X		
Dinophysis norvegica	X		
Dinophysis rotundata	X		
Dinophysis acuminata	X		
Dinophysis homunculus	X		
Dinophysis caudata	X		
CLASS			
Mastigophora (cont.)			
SUBCLASS			
Phytomastigoda (cont.)			
ORDER			
Dinoflagellida (cont.)			
Dinophysis ovata	X		
Phalacroma roseum	X		
Phalacroma rotundatum	X		
Diplopsalis lenticula	X		
Glenodinium trochoideum	X		
Oxyrrhis marina	X		
Amphidinium longum	X		
Amphidinium operculatum	X		
Amphidinium punctifera	X		
Amphidinium crassum	X		
Amphidinium fusiforme	X		
Gymnodinium punctatum	X		
Gymnodinium minor	X		
Gymnodinium achromaticum	X		
Gyrodinium fissum	X		
Gyrodinium pingue	X		
Polykrikos barnegatensis	X		
Polykrikos sp.	X		
Phytomonadida			
Pyramimonas reticulata	X		
Pyramimonas sp.	X	X	
Polytoma papillatum	X	X	
Polytomella sp.	X		
Collodictyon triciliatum	X		
Pedimonas minor	X	X	X
Chlamydomonas mikroplankton	X		
Chlamydomonas reinhardii	X		
Chlamydomonas sp.	X		

TABLE I (*Continued*)

	Floating	Attached or in Debris	From Bottom Samples
CLASS			
Mastigophora (cont.)			
SUBCLASS			
Phytomastigoda (cont.)			
ORDER			
Phytomonadida (cont.)			
Sphærella atlantica	X		
Sphærella marina	X		
Chlorogonium euchlora	X	X	
Hyalogonium acus	X	X	
Phacotus sp.	X	X	
Euglenidae			
Euglena gracilis	X		
Euglena sp.	X		
Trachelomonas euchlora	X		
Eutreptia viridis	X	X	
Euglenopsis sp.	X	X	
Astasia lagenula		X	X
Astasia sp.		X	X
Urceolus sabulosus		X	X
Peranema trichophorum		X	X
Petalomonas carinata		X	X
Petalomonas mediocanellata		X	X
Tropidoscyphus octacostatus		X	X
Distigma urceolaris		X	X
Heteronema acutissimum	X	X	X
Heteronema sp.		X	X
Notosolenus orbicularis	X	X	X
Notosolenus apocamptus		X	X
Anisonema ovale		X	X
Anisonema vitrea		X	X
Anisonema truncatum		X	X
Dinema grisoleum		X	X
Chloromonadida			
Thaumatomastix setifera	X	X	X
Gonyostomum depressum	X	X	

	Floating	Attached or in Debris	From Bottom Samples
CLASS			
Mastigophora (cont.)			
SUBCLASS			
Zoomastigoda			
ORDER			
Pantastomatida			
Multicilia lacustris	X	X	
Actinomonas sp.	X	X	
Cercomastix sp.		X	X
Mastigamœba longifilum		X	X
Mastigamœba socialis		X	X
Mastigella mitens		X	X
Bodopsis sp.		X	
Cercobodo crassicauda		X	X
Cercobodo longicauda		X	X
Cercobodo bodo	X	X	X
Cercobodo sp.		X	
Protomastigida			
Dallingeria drysdali	X	X	X
Monosiga ovata		X	
Salpingœca minuta		X	
Salpingœca sp.		X	
Bicocœca oculata		X	
Amphimonas globosa	X	X	X
Monas socialis	X	X	
Monas vivipara		X	X
Monas dangeardii		X	X
Bodo globosus		X	
Bodo lens		X	
Bodo ovatus		X	
Rhynchomonas sp.	X	X	X
Ancyromonas contorta	X	X	
Dinomonas vorax	X	X	
Pleuromonas jaculans		X	X
Oicomonas termo		X	X
Oicomonas socialis		X	
Polymastigida			
Tetramitus sp.	X	X	X
Hexamitus sp.	X	X	X
Trepomonas agilis	X	X	X

Table I (*Continued*)

	Floating	Attached or in Debris	From Bottom Samples
Class			
Infusoria			
Subclass			
Ciliata			
Order			
Holotrichida			
Holophrya discolor		X	X
Trachelocerca papillosa		X	X
Trachelocerca phœnicopterus		X	X
Trachelophyllum sp.		X	X
Lacrymaria lagenula	X	X	X
Lacrymaria olor		X	X
Blepharostoma pigerrima		X	X
Chœnia elongata		X	X
Chœnia teres		X	X
Prorodon teres		X	
Mesodinium rubrum	X	X	
Mesodinium pulex	X	X	
Lionotus cygnus		X	
Lionotus fœciola		X	
Loxodes rostrum		X	
Chlamydodon memosyne		X	X
Chilodon sp.	X	X	
Chilodon cucullulus	X	X	X
Nassula oblonga		X	
Nassula aurea		X	
Dysteria pusilla		X	
Dysteria armata		X	
Trochilia sigmoides		X	X
Ægyria olivia		X	X
Ægyria roseus		X	
Urocentrum turbo	X	X	X
Loxocephalus granulosus	X	X	
Uronema marina	X	X	
Frontonia leucas	X	X	
Glaucoma sp.	X	X	
Colpoda sp.	X	X	
Colpidium sp.	X	X	
Cinetochilum margaritaceum	X	X	X
Paramecium sp.		X	
Pleuronema chrysalis		X	
Class			
Infusoria (cont.)			
Subclass			
Ciliata (cont.)			
Order			
Holotrichida (cont.)			
Cyclidium glaucoma	X	X	X
Lembus pusillus	X	X	
Lembus infusionem	X	X	X
Lembus punctifera		X	
Plagiopyla nasuta		X	
Drepanomonas sp.		X	
Heterotrichida			
Folliculina ampulla		X	
Folliculina elegans		X	
Climacostomum sp.		X	
Condylostoma patens		X	X
Saprodinium sp.	X	X	
Oligotrichida			
Halteria grandinella	X	X	
Labœa spp.	X	X	
Strombidium sulcatum	X	X	
Strombidium grande	X	X	
Strombidium caudatum	X	X	
Tintinnopsis beroidea	X		
Tintinnopsis sp.	X		
Amphorella sp.	X	X	
Hypotrichida			
Peritromus emmæ		X	X
Oxytrichia pelionella		X	
Oxytrichia fallax		X	
Stylonichia mytilus		X	X
Epiclintes radiosa		X	
Epiclintes ambiguus		X	X
Epiclintes retracta		X	X
Amphisia kessleri		X	
Holosticha rubrum	X	X	X
Holosticha pernix		X	
Holosticha multinucleata		X	
Stichotricha secunda		X	X
Histrio pelionella		X	
Uroleptus pisces	X	X	
Uronychia setigera	X	X	
Uronychia transfuga		X	
Euplotes vannus		X	

Table I (*Continued*)

	Floating	Attached or in Debris	From Bottom Samples		Floating	Attached or in Debris	From Bottom Samples
Class				Class			
Infusoria (cont)				Infusoria (cont.)			
Subclass				Subclass			
Ciliata (cont.)				Ciliata (cont.)			
Order				Order			
Hypotrichida (cont.)				Peritrichida			
Euplotes harpa		X		*Vorticella* spp.		X	
Euplotes patella		X		*Rhabdostyla* spp.		X	
Diophrys norvegicus		X	X	*Cothurnia* spp.		X	
Diophrys excavatum		X		*Zoothamnium* spp.		X	
Diophrys appendiculatus		X		*Vaginicola* sp.		X	
				Subclass			
Aspidisca hexeris		X	X	Suctoria			
Aspidisca costata	X	X	X	*Acineta tuberosa*		X	
Aspidisca turrita		X		*Acineta* sp.		X	
Onychaspis polystyla		X		*Ephelota coronata*		X	
				Ephelota sp.		X	
Onychaspis leptaspis		X		*Podophrya fixa*		X	

By centrifuging known volumes of sea water and carefully decanting, the catch was concentrated for examining living animals. A Spencer binocular microscope with apochromatic equipment and a mechanical stage were used for this. A 60X water immersion objective proved very valuable, but the metallic mounting was quickly toxic to various Protozoa. Because a Sedgwick-Rafter cell did not permit careful examination or counting of small cells, several drops of a well mixed catch delivered by a calibrated pipette were studied for each sample. The only preserved samples studied were those secured on cruises.

Many forms were found which were already familiar as fresh water species, but many others were observed which could not be traced to previously described species. When one of these unfamiliar or apparently undescribed forms appeared in numbers and on more than one occasion an effort was made to study it as a new species.

Genera and Species Present

Table I lists 264 genera and species of Protozoa identified from the collections made during the summer of 1934. It will be noted that some groups are very scantily treated. Thus little attempt was made to identify the several species of amœbas which were found, and the few Radiolaria which appeared in the catches about the end of the summer were likewise not identified. No parasitic forms were studied and very little attention was paid to the Suctoria.

The Sarcodina were the least important group in variety and actual numbers found. The Ciliata formed a large and varied group on the bottom and in debris but only a few occurred as free swimming or floating forms. Dinoflagellida and Silicoflagellida were numerous but curiously very few Coccolithophora appeared. Colorless, often large, Euglenida were abundant in samples containing debris and at the bottom. The Pantastomatida were very common. Samples often swarmed with extremely large numbers of small flagellated Protozoa laborious to count and identify which were usually examined to see if they could be identified as *Bodo, Dallingeria* or such small species and were then treated simply as " small flagellates." Altogether it is the Flagellata which are of most importance as swimming and suspended forms.

Of the major groups of Protozoa as listed by Calkins (1926), the Woods Hole waters contain numerous species of each in abundance. This includes the nine free living orders of Mastigophora, and all orders of Infusoria, while the only order of the Sarcodina for which representatives were not identified is the Mycetozoa.

SEASONAL SUCCESSION

No great pulses of Protozoa were found comparable to the well-known succession of diatoms in the sea. Thus no group of Protozoa ever attained the volume content of *Chætoceros* or *Rhizosolenia* at any observed time in the summer of 1934. These large diatoms more than compensated by their size for any discrepancy in numbers between themselves and the small flagellates, for example.

Practically the only Protozoa showing any succession were the dinoflagellates and silicoflagellates. Radiolaria appeared in small numbers in late August and early September but most of the Sarcodina and Mastigophora and all of the Infusoria were present to some extent at all times. *Distephanus speculum* was the sole representative of its group in early June but later its numbers decreased and other genera and species of silicoflagellates appeared. *Tintinnopsis beroidea* varied greatly in numbers throughout the summer but some were always present. Very few dinoflagellates were present early in the summer but later they became the dominant forms. Thus *Ceratium tripos* was first observed June 24, but soon thereafter it was common, and the same was true of *Peridiniopsis*. The maximum for dinoflagellate species and numbers was about mid-August. No swarming of dinoflagellates occurred either, such as that observed by Martin and Nelson (1929) in Delaware Bay. Table II gives the numbers and seasonal occurrence of various groupings of Protozoa at Woods Hole in the summer of 1934.

Table II

Estimated numbers of Protozoa per liter of sea water showing seasonal occurrence for each of four species, five related groups and totals of all Protozoa occurring at a given sampling point in the Hole at Woods Hole in the summer of 1934.

Date	*Exuviaella lima*	*Prorocentrum micans*	*Distephanus speculum*	*Tintinnopsis beroidea*	Heliozoa	Euglenoid Flagellida	Total Dino-Flagellida	Total Flagellida	Total Ciliata	Total Protozoa
June 14...	1,500	375	7,875	1,500	—	—	13,875	25,500	1,875	27,375
" 16...	312	—	3,750	1,662	—	—	7,187	27,874	2,599	30,500
" 19...	1,270	—	3,810	—	—	—	5,715	115,555	300	115,855
" 21...	450	—	6,750	1,575	—	225	9,900	29,025	1,800	33,300
" 22...	1,575	—	4,725	5,250	—	—	8,400	27,825	5,250	33,075
" 23...	2,520	840	1,680	3,360	—	—	11,660	28,206	3,570	31,750
" 24...	5,940	—	3,780	1,080	—	—	13,500	58,320	1,620	59,940
" 27...	3,500	—	3,000	1,000	—	—	5,000	52,500	1,500	54,000
July 3...	5,500	4,000	8,500	8,500	—	3,000	23,000	53,750	12,500	69,250
" 10...	8,500	1,000	3,500	7,000	3,000	2,500	28,500	83,000	9,500	95,900
" 18...	6,500	2,750	2,750	3,250	3,250	3,250	15,500	90,250	4,750	100,500
" 31...	6,750	6,375	1,500	9,375	—	300	36,275	93,500	31,875	125,375
Aug. 8...	1,500	—	500	2,625	—	750	16,875	68,250	8,250	76,490
" 15...	5,250	5,625	—	9,750	1,500	4,175	46,875	178,125	15,750	135,375
" 22...	7,875	3,375	—	6,375	1,875	3,750	31,875	111,720	9,375	122,970
" 29...	6,750	5,250	—	7,500	2,250	1,500	40,875	102,395	13,875	119,270

Nature and Accumulation of Sea Floor Population

The rate at which the protistan flora and fauna become established on the bottom of the sea in summer, at least in shallow waters, is amazing. Syracuse dishes were suspended from the float enclosed in wire cages so that only very small organisms could have access to them. At stated periods a dish was removed, wiped clean underneath, and its contents examined with a water immersion objective. It was soon found that direct examination was no longer possible after 24 hours; sediment and organisms were too thick to see through after that interval. Table III gives the numbers of identified organisms which accumulated in a representative dish in 24 hours between July 9 and 10.

It will be seen from Table III that the population consisted of about one-third each of Protozoa, diatoms, algæ and fungi. In this average sample the number of organisms listed is smaller than the number actually accumulating in 24 hours. Some are out of the plane of observation, some are obscured by debris, some encyst in the allotted period, and some occur which cannot be identified. Small samples of film from such a Syracuse dish were examined and the only organisms which could be found were diatoms, amœbæ, the ciliates *Cyclidium* and

Lembus and the flagellates *Bodo* and *Rhynchomonas.* These samples were then added to filtered sea water enriched with nutrient materials and gave thriving cultures of several genera of diatoms; four species of amœbas; the ciliates *Uronychia, Cyclidium, Lembus, Holosticha, Euplotes charon* and *Euplotes patella* as well as some unidentified ciliates; *Oxyrrhis marina, Amphidinium operculatum* and another unidentified dinoflagellate, *Rhynchomonas, Bodo* and *Notosolenus;* and green, brown, red and blue-green algæ, these last being especially rich in number of species and abundance. Evidently the sea bottom shelters many organisms other than those in the trophic state, and to arrive at the true population one should augment visual examination of fresh samples with a variety of cultures designed to produce excystment and growth; the cultures above were produced on only one type of medium. Instead of accumulating a population of 144,000 Protozoa per square meter in 24 hours, the sea bottom at this shallow point might acquire many times that many.

TABLE III

Numbers of protistan organisms accumulating in 24 hours per square centimeter of exposed Syracuse dish. A typical sample.

Diatoms	16,120
Small algal cells	17,980
Fungi	2,480
Unidentified amœbeæ	2,400
Unidentified Heliozoa	620
Unidentified flagellates	5,580
Unidentified ciliates	310
Exuviælla lima	930
Gymnodinium sp.	620
Ceratium lineatus	240
Pyramimonas inconstans	1,240
Calycomonas sp.	2,480
Trachelomonas euchlora	240
Anisonema ovale	620
Notosolenus orbicularis	240
Chlamydodon memosyne	240
Cyclidium glaucoma	240
Tracheloccerca phœnicopterus	240
Euplotes patella	240
Aspidisca costata	240
Podophrya fixa	240
Total Protozoa per sq. cm.	17,060

The nature of the sea bottom largely determines the nature and rate of accumulation of its population. Sandy or current-swept bottoms might have a small population, except in crevices, depressions or other sheltered situations. In the Syracuse dishes representing a sheltered bottom a film was gradually built up during four weeks greatly reminiscent of the film accumulating on the stones of the trickling filter in a sewage disposal plant. It consisted of much debris but nematodes, hydroids, and other Metazoa were abundant in it. Its chief population, however, consisted of Protozoa and diatoms with a few filamentous algæ. The deeper parts of the film contained few Protozoa, the maximum population being in the porous upper part. Wherever such a thin blanket of film as this exists on the sea floor it must be of great importance in the mineralization of organic debris, which obviously occurs to the greatest extent only where such a film can be built up. The few samples obtained in 1934 from the sandy bottom of Vineyard Sound yielded few Protozoa, but samples from the mud banks in Great Harbor showed an abundance of flagellates and ciliates. Table IV shows the Protozoa identified from two such bottom samples, together with those obtained

TABLE IV

Protozoa in the surface film of two samples from muddy bottoms, and those obtained by towing five feet off bottom where one of the mud samples was obtained.

Buzzards Bay	Great Harbor
Forty-five foot depth	Nine-foot depth
Amœbeæ, three species	Amœbeæ, two species
Foraminifera, four species	Foraminifera, two species
Gromia lagenoides	*Shepheardiella tæniformis*
Anisonema vitrea	*Anisonema vitrea*
Dinema griseolum	*Anisonema* sp.
Distigma proteus	*Heteronema* sp.
Urceolus sabulosus	*Peranema trichophorum*
Monas amœbina	*Urceolus sabulosus*
Monas obliqua	*Mastigamœba longifilum*
Bodo globosus	*Monas vivipara*
Lionotus wrzesniowski	*Bodo angustus*
Loxodes rostrum	*Polytoma uvella*
Peritromus emmæ	*Prorocentrum triangulatum*
Trachelocerca phœnicopterus	*Rhodomonas baltica*
Oxytrichia fallax	*Cyclidium glaucoma*
Uroleptus pisces	*Prorodon* sp.
Diophrys excavatus	*Chlamydodon memosyne*
Tintinnopsis beroidea	*Trachelocerca phœnicopterus*
Unidentified ciliates, three species	Unidentified ciliate, one species

Towing. Buzzards Bay

Distephanus crux
Exuvaiella lima
Ceratium fusus
Gonyaulax triacantha
Peridiniopsis asymmetrica
Monas vivipara
Strombidium sulcatum
Ochromonas marina
Exuviælla marina
Ceratium lineatus
Peridinium divergens
Phalacroma roseum
Holophrya griseum
Tintinnopsis beroidea

from a towing just off the bottom in the same locality for comparison. Bottom-dwellers are largely holozoic or saprozoic, whereas those from towings in shallow water are largely holophytic or saprozoic. The small number of species from the bottom samples is accounted for by the fact that the core of mud in each case was about 18 mm. in diameter. No fresh cores from deep samples were examined in 1934, although a core four days old from a depth of 200 meters contained numerous *Bodo* and *Anisonema* and a new species of *Prorodon.*

The Role of the Protozoa

It seems generally agreed that the Protozoa are important as a food source for other organisms in the sea, especially such animals as copepods. Examination of the gut contents of salps and copepods generally shows an abundance of diatom and dinoflagellate shells as well as those of Tintinnoidea. But such examinations reveal nothing about the use of naked dinoflagellates, and the smaller ciliates and flagellates; they disintegrate and leave no recognizable remains in the gut. I am of the opinion that these two latter types are more important in shallow waters than the shelled forms because of their abundance, and also because the large diatoms like *Chætoceros* and *Rhizosolenia,* which were exceptionally numerous at Woods Hole in 1934, cannot be ingested by the smaller copepods. Direct observation is not very practical, but small copepods were seen feeding on the bacteria and Protozoa in laboratory cultures in July and six months later were abundant in those cultures containing few diatoms but abundant bacteria and Protozoa. Clarke (1935) has proved that copepods use these minute cells as food, and from Table II it may be inferred that they are sufficiently numerous at all times in the summer to serve as food. If these very small protozoan cells are considered to be roughly spherical, an individual 5 microns in diameter would have a volume of 65.45 cubic microns, and a liter could contain roughly 15^{12} such individuals, so that a population of 300,000 per liter which has been noted at Woods Hole would still be a relatively sparse one. Nevertheless, the feeding mechanism of such animals as salps and copepods is perhaps capable of straining out these food organisms and the rapidity of cell division of these small forms permits a speedy recovery.

Nelson (1935) cites the importance of the dinoflagellates as food for oysters and has successfully experimented with the feeding of them to oysters. In areas such as the New Jersey coastal waters where the dinoflagellate population is great they may have a decided importance for this reason. Undoubtedly more careful investigation of the food of many marine animals will reveal a larger rôle of the Protozoa as food organisms.

The Protozoa also have an important function in the turnover of organic matter; this is not separable from their function as food-forming organisms. Dr. C. J. Fish remarked to me, "There must be numerous Protozoa in the surface waters; if a dead copepod is taken while over Georges Bank and allowed to stand in sea water from the same source, it is quickly attacked by a swarm of Protozoa." This is an easily made observation. Bacteria swarm about the dead animal also and they and the Protozoa penetrate inside the exoskeleton where they are not swept away by currents; there they work rapidly and soon only the chitinous shell remains. Often the visible Protozoa are so thick inside that their volume must be many times that of the decay bacteria. Direct observation is inadequate as proof that they actually ingest the flesh of the dead animal, but a *Loxophyllum* quickly becomes filled with round bodies, presumably stored food, while a *Lembus infusionem* can be seen forming food vacuoles containing ingested bacteria. The larger ciliates may feed on bacteria or on diatoms or other Protozoa and are themselves sizeable food morsels, as a species of *Chænia* and one of *Trachelocerca* each over 1,500 microns long. The holozoic and saprozoic forms attack organic debris in suspension or on the ocean floor and constantly convert it to protoplasm in part and accomplish its mineralization in part. If they do not compare with the bacteria in numbers, their size is a compensation for this.

Some Protozoa, especially the smaller ones, may be a part of the food chain by partly acting as "food condensers." Butterfield (1933) has shown that some bacteria thrive in a food medium too dilute for the ciliate *Colpidium,* which alone requires 500 mg. per liter of certain substances, but which will grow on 5 mg. per liter of these substances if *Bacillus ærogenes* is present, the bacterium apparently "condensing" the dilute food substances and being eaten in turn by the ciliate. It seems probable that the numerous smaller and presumably saprozoic flagellates may condense food in the sea in a similar manner, and in turn become food for larger forms.

The photosynthetic activities of the Protozoa are also important. The pigmented forms are numerous, and have a separate value in the food chain because of their utilization of inorganic matter. This work of those containing chlorophyll is self evident, but many brown, red and other coloring matters are found in the various groups, and the functions of these coloring matters is unknown. In the Woods Hole area pigmented Rhizopoda are principally Heliozoa and few in number, but pelagic Radiolaria containing the yellow symbiotic flagellate, *Chrysi-*

della, are abundant in the open sea. Among the flagellates four of the orders contain many pigmented forms, the most important being the Dinoflagellida. Chlorophyll is practically lacking in the marine Infusoria but other colors are not.

The elaboration of glucose and subsequent products by these pigmented forms must be evaluated in any consideration of the carbon content of the sea. Furthermore, the depths at which the pigment-bearers are found must be investigated, especially since they are active and rapid swimmers and are more independent of flotation mechanisms than the diatoms.

CONCLUSIONS

Systematic examination of the waters in the Woods Hole area has shown the existence of a large protozoan population from early June to mid-September. The population of this shallow tide-swept area is probably greater than hitherto suspected and must have a considerable ecologic importance because of its numbers, ability to reproduce rapidly, place in the food cycle, and furtherance of mineralization of organic debris. Scant examination of the off-shore waters indicates that the large inshore numbers are approximated in these off-shore waters also. Chlorophyll and other pigment-bearing forms predominate near the surface while at the bottom bacterial feeders and saprozoic forms are most abundant. Changes in the dinoflagellate population suggest seasonal succession but no such changes were observed among other types. The fauna at the bottom accumulates rapidly when protected and its members are active in the constant mineralization of the deposited debris. The maximum numbers in this film are determined by its thickness and rate of deposition. A weekly census of organisms present was kept, and a check list of the genera and species observed in the area has been made.

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DECOMPOSITION OF ORGANIC MATTER IN SEA WATER BY BACTERIA

III. Factors Influencing the Rate of Decomposition [1]

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The question has been raised by Krogh (1934*a*, *b*) and other investigators, whether or not the organic matter in sea water can be utilized by bacteria and can be broken down with the liberation of the constituent elements in mineralized forms. It has been previously reported (Waksman and Carey, 1935*a* and *b*) that the organic matter in sea water is not in a resistant state, but can be readily attacked by the bacteria found in natural water, when this water is placed under favorable conditions. These investigations have further brought out the fact that this organic matter is sufficient to support an active bacterial population. The rapidity of decomposition of the organic matter by bacteria is most conveniently determined by the rate of oxygen consumption in the water and by the liberation of the nitrogen in an available form; the latter process can best be measured in an indirect manner, namely by the decomposition of a non-nitrogenous organic substance, such as glucose, added to the water, since the process of glucose decomposition was found to be controlled by the concentration of available nitrogen or by the rate of its liberation. It was thus calculated that about fifty per cent of the total organic matter in the water is readily attacked by the bacteria, under favorable conditions; of this decomposed organic matter, about sixty per cent is completely oxidized and about forty per cent converted into bacterial cell substance.

Among the factors influencing the rate and extent of decomposition of the organic matter in the water, the following were found to be of paramount importance: 1. The temperature of the water; the lower the temperature, the smaller is the amount of organic matter decomposed in a given period of time or the longer does it take to bring about the same degree of decomposition. When water taken in the neighborhood of Woods Hole was placed at definite temperatures, in closed containers, the amount of oxygen consumed in 6 days, per liter of water, was 0.26 cc. at 2° C., 0.83 cc. at 12°, 1.39 cc. at 22° and 1.14 cc. at 34° C. 2. Abundance of available organic matter. This was demonstrated by the fact that when water was filtered through different types of filters, which tended to remove some of the suspended organic matter, such as Seitz filters, the rate of decomposition of the organic matter, as measured by the amount of oxygen consumed in a given period of time, was considerably reduced. 3. The water mass itself, as modified by distance from bottom, by its relation to photosynthetic zone, by latitude, by movements, especially oceanic circulation and vertical mixing. In water taken from the Gulf of Maine, the greatest oxygen consumption took place at a depth of 40 meters, while at Georges Bank, with greater vertical circulation, in the water just above the bottom. 4. Concentration of available inorganic nutrients; the influence of available nitrogen upon the decomposition of carbohydrates has already been mentioned; certain preliminary investigations also point to the significance, in this process, of available phosphorus.

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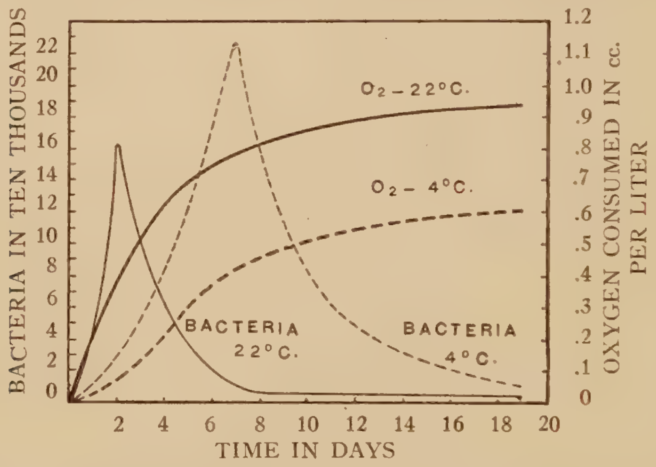

FIG. 1. Influence of temperature upon bacterial development and oxygen consumption in sea water.

Influence of Temperature

In order to illustrate further the effect of temperature upon the course of bacterial development and oxygen consumption, the results of a detailed and controlled experiment are reported in Fig. 1. The oxygen bottles were incubated under water. Although the maximum rate of bacterial development was reached as 22° C., within 2 days, and at 4° C., within 7 days, the consumption of oxygen continued even after that maximum was attained. The ratio between the periods of maximum bacterial development at the two temperatures was about 4 : 1. It is interesting to note that exactly the same amount of oxygen was consumed at both temperatures when this maximum was attained, namely 0.45 cc. per liter at 22° C. and 0.47 cc. at 4° C.

Influence of Organic Compounds

The second experiment illustrates the effect of two different forms of nitrogen upon the decomposition of a non-nitrogenous organic substance (glucose) added to sea water (Table I). In all cases, the water received 2 mgm. K_2HPO_4 per liter, to eliminate any effect due to a lack of available phosphorus in the water. The initial water contained 1,050 bacteria in 1 cc. and 5.43 cc. of oxygen per liter; the water was incubated at 22° C. In the decomposition of glucose added to sea water, the available nitrogen is definitely shown to be an important controlling factor; in the absence of available nitrogen, the addition of glucose did not result in any appreciable increase in oxygen consumption and bacterial development within three days, namely the time of most active bacterial multiplication in stored sea water; at a later period, however, active glucose decomposition sets in. However, there was still insufficient nitrogen available from the

TABLE I

Influence of nitrate and ammonia nitrogen upon the decomposition of glucose in sea water *

Glucose added	Source of nitrogen	Amount of nitrogen added	Bacteria in 1 cc.		Oxygen consumed	
			3 days	7 days	3 days	7 days
mgm. per liter		*mgm. per liter*			*cc. per liter*	*cc. per liter*
0	0	0	360,000	25,500	0.54	0.73
0	$NaNO_3$	0.1	345,000	17,000	0.52	0.69
0	$(NH_4)_2SO_4$	0.1	540,000	15,500	0.60	0.91
1.5	0	0	515,000	54,000	0.65	1.32
3.0	0	0	384,000	44,000	0.72	1.54
6.0	0	0	340,000	52,000	0.64	1.54
1.5	$NaNO_3$	0.1	1,930,000	42,500	0.95	1.27
3.0	$NaNO_3$	0.1	1,650,000	7,000	1.79	2.43
6.0	$NaNO_3$	0.2	3,200,000	7,200	2.74	3.69
1.5	$(NH_4)_2SO_4$	0.1	1,750,000	7,800	1.27	2.10
3.0	$(NH_4)_2SO_4$	0.1	1,880,000	6,000	1.76	2.37
6.0	$(NH_4)_2SO_4$	0.2	4,600,000	24,000	2.72	3.77

* Fresh water contained 1,050 bacteria in 1 cc. and 5.43 cc. oxygen per liter; bottles incubated at room temperature.

decomposition of the organic matter in the water, even after 7 days, to result in the oxidation of appreciable quantities of glucose; when 1.5 mgm. glucose was added per liter, the increase in oxygen consumption was 0.59 cc.; with another 1.5 mgm. glucose, the increase was only 0.22 cc., while the third portion of 1.5 mgm. glucose brought no further increase at all. It is interesting to note that the oxidation of glucose in 7 days resulted in an increase in oxygen consumption just about equivalent to that which took place in the water itself. The addition of 0.1 or 0.2 mgm. nitrogen to the water receiving the glucose greatly increased the rate of its decomposition. The two sources of nitrogen had about the same effect upon the rapidity of utilization of glucose by bacteria.

TABLE II

Oxygen consumption in the decomposition of amino acids in sea water by bacteria

Compound	Amount added	Oxygen consumed, cc. per liter			Theoretical oxygen required for complete oxidation of 1 mgm. of compound *	Bacteria in 1 cc.
		2 days	5 days	Per 1 mgm. of amino compound used		2 days
	mgm. per liter					
Water alone	—	0.71	1.01	—	—	820,000
Glycocoll	2	0.65	1.19	—	—	1,100,000
Glycocoll	4	1.42	1.95	0.38	0.64	2,050,000
Alanine	2	1.39	2.03	—	—	1,600,000
Alanine	4	2.03	2.94	0.46	1.08	3,700,000
α-Phenylalanine	2	2.08	2.77	—	—	950,000
α-Phenylalanine	4	3.66	4.95	1.09	1.93	1,200,000
Glutamic acid	2	1.31	1.78	—	—	1,950,000
Glutamic acid	4	2.30	3.24	0.73	0.98	3,550,000
Tyrosine	2	1.99	2.59	—	—	1,090,000
Tyrosine	4	3.57	4.58	1.00	1.68	1,600,000
Asparagine	2	0.82	1.23	—	—	1,120,000
Asparagine	4	1.32	1.97	0.37	0.73	2,100,000

* For complete oxidation of compound, assuming that nitrogen is left as ammonia.

The consumption of oxygen takes place not only at the expense of the carbohydrates in the water, but also in the decomposition and oxidation of the organic nitrogenous constituents, as brought out in Table II. Four amino acids, namely glycocoll, *d*-alanine, α-phenylalanine, *d*-glutamic acid and tyrosine, and asparagine, were added to fresh sea water, in concentrations of two and four milligrams per liter. Consumption of oxygen and bacterial multiplication were determined, after two and five days incubation of the water, in the dark at 20° C.

For the calculation of the amount of oxygen consumed per unit of nitrogenous compound, the results obtained after five days incubation were used. The increase in oxidation for the addition of 4 milligrams of compound above the water receiving the 2-milligram portions was used as basis of interpretation of the results. This experiment brought out the fact that various simple nitrogenous compounds are readily oxidized by marine bacteria in sea water; a half or more of the theoretical amount of the different compounds was destroyed in 5 days, as measured by the amount of oxygen consumed; the rate of oxidation of the various compounds was found to vary with their specific chemical nature. These results tend to explain the rapid rate of decomposition of zoöplankton in sea water, as compared with that of the marine algæ (Waksman, Carey and Reuszer, 1933). Because of the greater proportion of available nitrogen in the former, their decomposition is accompanied by the liberation of nitrogen in the form of ammonia or as other simple compounds, while the decomposition of the second is accompanied by nitrogen consumption. The importance of the carbon-nitrogen ratio of the organic complex is evident. Substances with a narrow ratio will, on decomposition, result in a rapid liberation of the nitrogen. This nitrogen is partly utilized by the bacteria in the process of decomposition of the carbohydrates and is partly left in the water in a form available for the growth of the algal and diatom populations.

TABLE III

Influence of light upon bacterial development

Incubation	Oxygen, cc. per liter		Bacteria in 1 cc.	
Days	Dark	Light	Dark	Light
0	5.60	5.60	3,580	3,580
2	5.40	5.91	10,500	130,000
4	5.10	5.69	2,500	11,000
6	5.17	6.50	2,200	8,500
9	4.86	6.69	6,500	9,600
12	4.72	6.97	15,000	14,200

Relationship of Photosynthesis and Phytoplankton Development to Bacterial Activities in Sea Water

A parallel development of diatoms and bacteria in sea water has previously been reported (Gran, 1933, and Waksman et al, 1933). It is quite likely that this is due primarily to the fact that the bacteria

TABLE IV

Rapidity of bacterial decomposition of freshly synthesized plant substances

Incubation	Oxygen, cc. per liter			Bacteria in 1 cc.		
Days	Dark	Light	Light followed by dark for 5 days	Dark	Light	Light followed by dark for 5 days
0	5.41	5.41	—	10,000	10,000	—
3	4.95	5.67	5.04	28,000	17,000	14,500
6	4.79	5.52	?	9,000	19,500	?
10	4.55	5.84	5.43	7,100	6,000	9,500
20	4.47	6.96	5.91	20,500	13,000	18,300
30	4.30	7.60	—	17,500	9,000	—

feed either upon the organic substances secreted by the diatoms or upon those cells which, because of mechanical disintegration, become subject to bacterial attack. Fresh sea water was placed in oxygen bottles; some of these were incubated in the darkness at room temperature and under water, and some were exposed to the light, also under water. At definite intervals, some of the bottles were removed and analyzed for oxygen and bacterial numbers (Table III). The results show that continued decomposition of the organic matter took place in the darkness, while, in the light, organic synthesis predominated, as shown by the liberation of oxygen; the newly synthesized material supported a more abundant bacterial population.

TABLE V

Synthesis and decomposition of organic matter in sea water

Incubation, days		Oxygen, cc. per liter			Bacteria in 1 cc.		
Harbor	Laboratory	Dark	Light	Light followed by dark	Dark	Light	Light followed by dark
0*	—	5.80	5.80	—	—	—	—
7	7	4.60	6.19	5.01	—	—	—
7	14	—	—	4.05	—	—	—
0†	—	5.37	5.37	—	—	—	—
7	9	4.59	6.11	5.01	2,000	14,630	46,900
7	18	—	—	4.11	—	—	17,250

* Experiment begun on July 27.

† Experiment begun on August 10.

In order to demonstrate to what extent this freshly synthesized organic matter can be decomposed by the bacteria in the water, the above experiment was repeated. Some of the bottles, after exposure to light for varying periods of time, were incubated, for a period of 5 days, in the darkness (Table IV). The synthesized organic substances are found to be readily subject to bacterial decomposition, as shown by the rapid reduction in the oxygen, when photosynthesis is excluded.

The results of two other experiments are reported in Table V. Sea water was placed in light and dark bottles and incubated directly in the harbor, about five feet below the surface; a modified procedure of Winberg (1934) was employed. Here as well, some of the bottles, which have been exposed to light in the harbor for a period of 7 days were later incubated in the darkness, for varying periods of time. The temperature of the outside water was about 15° C. and of the tank in laboratory, about 20° C. The newly synthesized organic matter was again found to be rapidly decomposed, as shown by the disappearance of the oxygen and by the increase in bacterial multiplication, when photosynthesis was stopped.

TABLE VI

Decomposition of organic matter in water from Gulf of Maine and Georges Bank, in the spring *

Station number	Depth	Temperature of water	Bacteria in 1 cc. of water	Water incubated for 5 days at room temperature			
				Water alone		Water and glucose †	
				Oxygen consumed	Bacteria in 1 cc.	Oxygen consumed	Bacteria in 1 cc.
	meters	° *C.*		*cc. per liter*		*cc. per liter*	
2441	5	7.5	—	1.28	621,000	3.68	1,375,000
2441	50	4.3	—	0.79	77,500	1.44	99,000
2441	225	5.8	—	0.71	24,000	1.30	—
2442	5	7.0	55	0.88	200,000	1.08	164,000
2442	50	3.9	8.5	0.66	48,300	1.46	714,000
2442	225	5.6	1	0.48	79,500	0.57	79,000
2443	5	6.9	2	1.00	27,400	1.69	71,000
2443	25	7.9	7	0.77	36,000	1.11	36,000
2444	5	6.35	19	0.98	96,000	1.13	101,500
2444	33	6.44	8	0.52	18,000	0.97	85,500

* Samples taken on May 20, 1935.

† Two mgm. per liter.

Decomposition of Organic Matter in Sea Water at Different Seasons of Year and at Different Latitudes

An attempt can now be made to interpret the results obtained on the decomposition of the organic matter in sea water taken from a group of stations, at different depths, and at different seasons of the year. Water taken in the spring of the year from both deep (Gulf of Maine) and shallow (Georges Bank) stations showed the largest amount of rapidly decomposing organic matter at the surface, gradually decreasing with depth (Table VI). The amount of oxygen consumed in the presence of glucose was, on the average, just about twice as high as in the water alone; this would tend to confirm the previous conclusions concerning the liberation of an equivalent amount of nitrogen in an available form, in the decomposition of organic matter in sea water. Water taken from the Gulf of Maine stations, in the late summer and fall, showed an increase in readily decomposable organic matter with increasing depth, then decreasing again in the water nearer to the bottom; the same was true also of the water taken in the Gulf of Maine stations during the following summer (Table VII).

TABLE VII

Bacterial activities in the water of the Gulf of Maine in summer and fall

Date of sampling of water	Depth	Water incubated 5 days at room temperature	
		Oxygen consumed	Bacteria in 1 cc.
	meters	*cc. per liter*	
August 5, 1934	5	0.86	—
August 5, 1934	40	1.26	—
August 5, 1934	229	1.45	—
November 22, 1934	5	0.43	34,000
November 22, 1934	40	0.90	102,500
November 22, 1934	236	0.70	244,000
November 22, 1934	5	0.64	130,000
November 22, 1934	40	0.72	140,500
November 22, 1934	213	0.59	211,500
July 8, 1935 *	0	0.42	225,000
July 8, 1935	50	1.02	182,300
July 8, 1935	125	0.67	214,000
July 8, 1935	0	0.13	373,000
July 8, 1935	50	0.77	339,000
July 8, 1935	200	0.35	191,000

* Incubation of water, 3 days.

Several stations were taken, during the winter of 1935, from Cape Cod Light to Bermuda; the rate of oxygen consumption and bacterial multiplication in the water from those stations, kept in closed bottles at a given temperature (18–22° C.) and for a certain period of time (5 days), was determined. The water was filtered through sterile sand filters, so as to eliminate the interference of coarser material. The amount of oxygen consumed was reduced appreciably by the filtration process, namely, in one test from 0.70 to 0.35 cc. per liter and in another from 1.26 to 0.74; this was due to the fact that the readily decomposable larger diatoms, protozoans and other forms of life were removed. The most striking result of these experiments (Table VIII) is the poverty of the waters close to Bermuda. Although sufficient bacteria were found in the water and especially in the bottom material (174,000 bacteria in 1 gram of fresh material), there was not sufficient organic matter to support active bacterial development.

TABLE VIII

Oxygen consumption in water taken from a series of stations from Cape Cod to Bermuda

Station number	Position	Depth	Temperature	Oxygen consumed*	Bacteria in 1 cc.	
					Start	5 days
		meters	° *C.*	*cc. per liter*		
2308	42° 21′ × 69° 34′	5	5.2	0.74	414	550,000
2309	42° 32′ × 69° 13′	5	5.2	1.00	614	213,750
2310	41° 27′ × 69° 33′	5	4.3	0.92	83	65,800
2311	41° 18′ × 69° 21′	5	4.5	0.96	68	132,000
2312	40° 12′ × 68° 21′	5	9.4	—	141	215,000
2312	40° 12′ × 68° 21′	50	5.4	0.83	399	207,500
2312	40° 12′ × 68° 21′	190	3.4	0.95	3,000	375,000
2313	38° 25′ × 68° 18′	5	11.8	0.63	52	169,000
2314	38° 20′ × 68° 17′	5	20.0	0.78	62	347,000
2315	37° 42′ × 68° 02′	5	21.5	0.62	412	204,000
2316	36° 09′ × 67° 30′	5	18.5	0.75	52	78,200
2317	33° 56′ × 65° 52′	5	19.1	0.10	66	79,000
Grog's Harbor, Bermuda		1–6	17.0	0.24	78	16,500

* Five days incubation at room temperature.

Influence of Oxygen Tension

The concentration of oxygen in the water was previously found (Waksman and Carey, 1935*a*) to have an important influence upon bacterial activities and upon oxygen consumption, when the water was allowed to incubate. Those results were obtained by the use of Seitz-filtered water. It was found in subsequent studies that this filtration process removes a large part of the suspended and readily decomposable organic matter in the water, thus modifying considerably the extent of decomposition of the organic matter. This is illustrated in Table IX. In the unfiltered water, the organic matter decomposed readily even at the lowest concentration of oxygen; in the Seitz-filtered water, however, the amount of organic matter decomposed with a low oxygen content was much less. With an increase in the concentration of oxygen in the water, the rate of organic matter decomposition, although remaining less in the filtered water, approaches that of the unfiltered water. These results tend to establish certain facts: (*a*) the small amount of organic matter removed by filtration through Seitz filters undergoes rapid decomposition; (*b*) the oxygen tension required for the decomposition of the organic matter passing through the filter is greater; (*c*) the type of the bacteria developing on the organic matter in the Seitz-filtered water is different, as shown by the fact that much larger numbers are produced accompanied by a much smaller amount of oxygen consumed. The difference in the numbers of bacteria given by filtered and unfiltered water may point to radical differences in the chemical nature of the two fractions of the organic matter in the water. This confirms some observations previously reported (Waksman and Carey, 1935*a*).

TABLE IX

Influence of oxygen tension in unfiltered and Seitz-filtered sea water upon bacterial activities

Treatment of water	Unfiltered water				Seitz-filtered water			
Oxygen content at start, cc. per liter	0.57	2.66	4.97	5.28	1.14	2.38	2.89	4.94
Oxygen content, after 8 days	0.05	2.16	4.24	4.61	0.89	2.07	2.50	4.40
Oxygen consumed	0.52	0.50	0.73	0.67	0.25	0.31	0.39	0.54
Bacteria in 1 cc., after 8 days	11,500	7,000	2,150	1,300	9,000	230,000	122,000	102,000

Continued Decomposition of Organic Matter in Stored Water

In all previous experiments, only short incubation periods were employed. The question naturally arises as to what happens when prolonged periods of incubation are used. In order to determine this effect, three large carboys were carefully washed and filled with sea water as follows: (*a*) fresh water from Woods Hole Harbor, (*b*) same water filtered through a column of washed sterile sand, (*c*) fresh water from Gulf of Maine. Once a week, 1,200-cc. portions of water were removed and placed in oxygen bottles; the amount of oxygen absorbed in 7 days, by incubating the water in the dark, was then determined. The carboys were well shaken every day so as to increase the oxygen content of the water. The results (Fig. 2) show that the unfiltered harbor water gave the greatest amount of decomposition and that the rate of decomposition of the organic matter in the water was gradually reduced. The total amount decomposed in 6 weeks per liter of water, in terms of oxygen consumed, was 1.64 for the unfiltered harbor water, 1.19 for the filtered harbor water and 1.24 for the Gulf of Maine water.

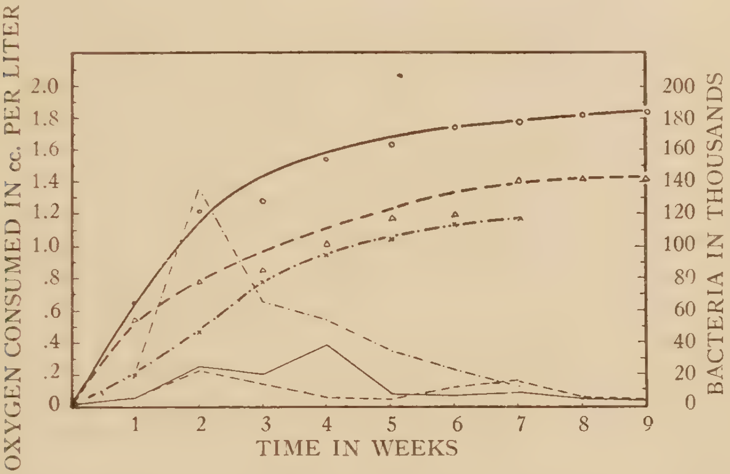

FIG. 2. Changes in bacterial numbers and oxygen consumption upon continued decomposition of organic matter in sea water. Heavy lines represent oxygen consumption; light lines, bacterial numbers. Heavy unbroken line, curve for unfiltered water from Woods Hole; heavy broken line, curve for filtered water from Woods Hole; ·—· represents curve for unfiltered water from Gulf of Maine.

SUMMARY

1. Investigations are reported on the decomposition of organic matter in sea water placed under controlled laboratory conditions. It has been found that, under these conditions, the organic matter in the water, both in suspension and in solution, can undergo rapid decomposition. It is quite possible that a change in temperature, resulting from the sudden warming up of the water, may bring about not only an increase in the biological reactions, but also a change in their very nature; this limitation need not invalidate the results obtained, since these results are not a measure of what actually

happens in nature under different conditions, but what may happen under any one set of conditions.

2. The abundance of readily decomposable organic matter in sea water was measured by the rate of oxygen absorption in the water, incubated under uniform conditions. The rapidity of liberation of nitrogen in the decomposition of the organic matter can be measured by the rate of decomposition of glucose added to the water.

3. The amount of organic matter in sea water readily attacked by bacteria varies with the rate of production of the organic matter, with photosynthesis and with the water mass; at the surface of the water, it falls off as one goes southward.

The authors are indebted to Mr. T. C. Cordon, for assistance in making the oxygen determinations.

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GEOLOGY AND PALEONTOLOGY OF THE GEORGES BANK CANYONS

Part I. GEOLOGY

BY HENRY C. STETSON

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INTRODUCTION

Georges Bank is the westernmost of the important series of fishing grounds reaching from the southern New England coast past Nova Scotia to the Grand Banks of Newfoundland. During the summers of 1930 and 1932 the United States Coast and Geodetic Survey re-charted this bank for the benefit of the fishing industry. Sonic methods were used, which permitted numerous, closely spaced soundings. During the course of the survey, many gorges were found cutting the southern edge of the bank, which here is coincident with the edge of the continent. A few of these gorges had been indicated in a general way on the older charts, but this last survey was detailed enough to give for the first time their true configuration, as well as bring to light many others whose existence previously had not been suspected. In general, they are cut back into the continental shelf from 5 to 12 miles and are from about 2 to as much as 6 miles in width. Their floors range from approximately 1200 to more than 8000 feet below present sea level. All trace of them is lost in depths of less than 50 fathoms. The charts indicate that similar gorges indent the continental margin at various places from Cape Hatteras to the Grand Banks. Three off the Delaware-Maryland coast have recently been surveyed in enough detail to indicate that they are of the same type, and one of these has been traced to nearly 1500 fathoms. Although this study is concerned specifically with the canyons of Georges Bank, it must be borne in mind that conditions which produced them have affected a large portion of the eastern continental slope.

In places the slope of the valley walls is considerably above the angle of repose for unconsolidated material, which indicates that these walls consist of rock. Hence, the gorges afford an opportunity of obtaining specimens of the material of which the continental margin is composed, and, should it prove fossiliferous, of fixing at least the maximum age of the topographic features. If the gorges be due to stream cutting, tectonic movements of considerable magnitude can likewise be dated. Elsewhere, the rocks composing the shelf are mantled with a veneer of recent sediments, too thick to be penetrated. Numerous fragments containing fossils have been found on Georges Bank, but none had ever before been taken in place. With this in mind, the Woods Hole Oceanographic Institution, in August, 1934, sent the research vessel, *Atlantis*, on a dredging trip to three of the recently charted canyons cutting the southern edge of the bank between 67°38′ and 68°11′ W. Long. (Fig. 1).

The paleontological results of this study appear as separate sections of this report under their respective authors: J. A. Cushman, foraminifera; L. W. Stephenson, mollusks and echinoderms; R. S. Bassler, bryozoa. Thanks are also due to C. Iselin, J. L. Hough, and Marshall Schalk, for assistance at sea, and to Professor P. E. Raymond and Professor Kirk Bryan, of Harvard University, for much helpful advice.

FIELD METHODS

The dredge employed for this work was of the scraper type commonly used for biological collecting, but of much heavier construction. It is made of ¾-inch steel plates, welded at the corners. The outside dimen-

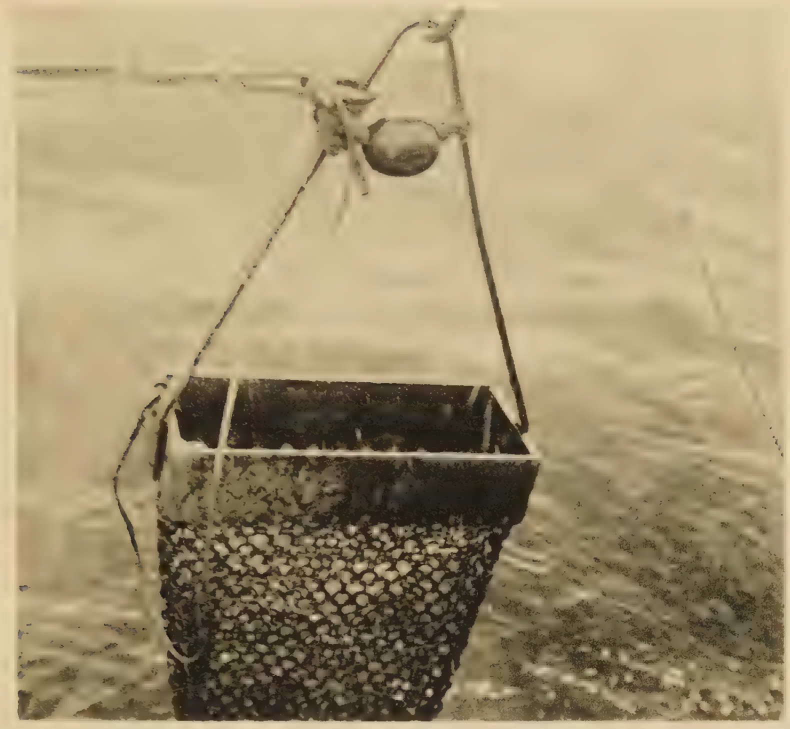


FIGURE 1. DREDGE USED IN OBTAINING SAMPLES FROM CANYON WALLS

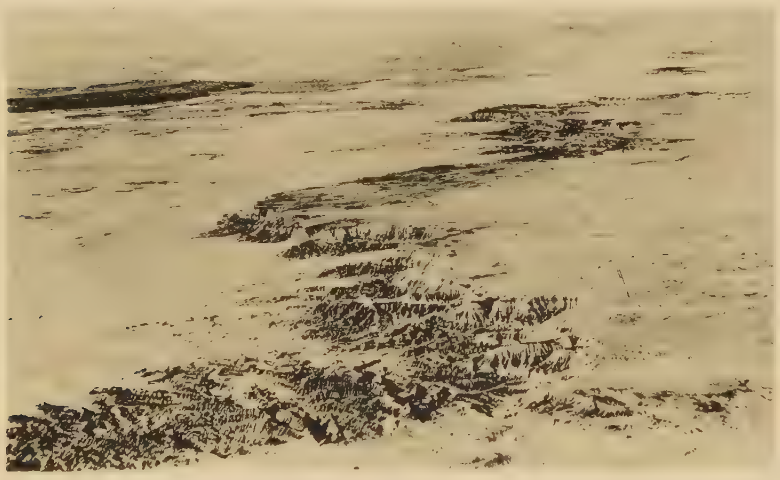
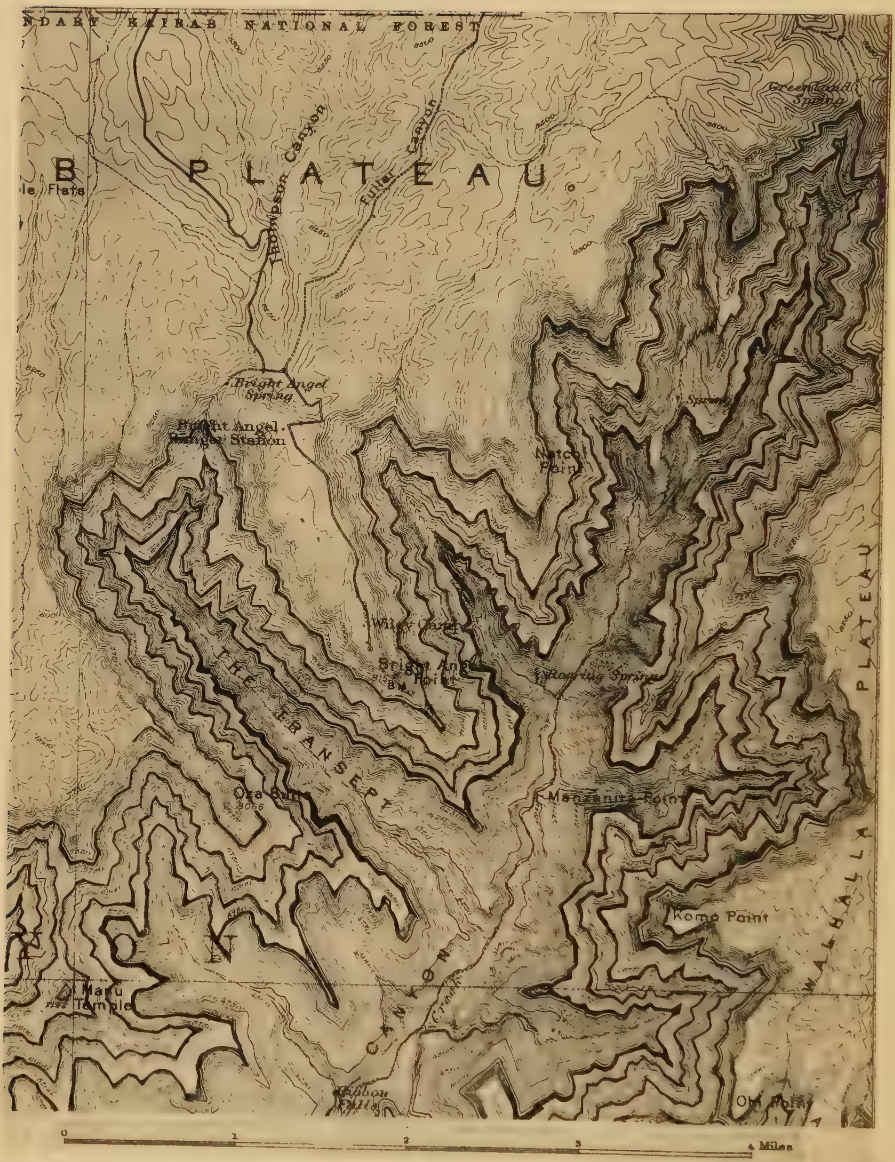


FIGURE 2. EROSIONAL PROCESSES

Scarp, about 15 miles southeast of Cameron, Arizona, showing the processes at work which may have produced similar-appearing submarine valleys on Georges Bank. Taken from an altitude of about 5000 feet. (Photo by Barnum Brown, American Museum-Sinclair Aerial Survey, 1934.)



PORTION OF BRIGHT ANGEL QUADRANGLE

United States Geological Survey sheet of the Grand Canyon, Coconino County, Arizona. Note similarity in configuration to the canyons of Georges Bank.

sions are 35 by 18 by 8 inches. The end pieces were cut with a taper, giving a slight flare toward the mouth, to facilitate the bite of the beveled cutting edges. The bail consisted of an iron strap, ½ by 2½ inches, welded to the sides. In practice it was found that weights lashed at the outer ends of the arms helped to keep the dredge in the proper towing position. A short rope was used to fasten the towing wire to the arms. If the dredge became securely hung, this rope, with a breaking strength of 12,000 pounds, would part before the wire. With the rope broken, the strain would fall on the tripping wires, which, being shackled to a corner of the dredge, would upset it and pull it clear. The bag, about four feet long, was of the link and ring type commonly used by scallop fishermen (Pl. 1, fig. 1).

Dredging operations were carried on in the following manner. The edge of a canyon was located by echo soundings and marked with a buoy. The vessel would proceed slowly across the canyon until a steep cliff had been crossed; then the course would be reversed, the dredge lowered, and the depth recorded. The ship would then go ahead at the rate of about 2 knots per hour, laying out wire at the same speed to avoid kinking, the dredge meanwhile remaining stationary. Experience showed that about one mile of wire was necessary to insure a good angle of drag for this type of work at the depths at which the cliffs were found. When sufficient wire was out, the winch was stopped and the dredge was dragged up the face of the cliff. The towing wire from the main winch ran over a combination meter wheel and strain indicator. By watching the latter instrument the operator could tell whether he was scraping through Recent, unconsolidated material or whether he had encountered bed rock. In the former case, even though cutting through glacial outwash with erratics a foot in diameter, the indicator never showed a strain of more than 3000 pounds. When the older, more consolidated deposits were encountered the strain varied from about 7500 to somewhat over 10,000 pounds. During the course of a tow, the strain would often approach the limit, and then suddenly would lessen as the dredge crossed successive outcrops, breaking pieces from them on the way. This explains why a single tow often yielded fragments very different in lithology and fauna. At times the dredge would anchor itself securely enough to check the vessel's headway. Then, the towing wire would be taken in until it was straight up and down, and the dredge could usually be loosened without parting the rope safety link and dumping the contents of the bag. With a mouth opening of 34½ by 16½ inches, it is obvious that loose fragments would not subject the gear to heavy strains. The glacial erratics brought up, several of which approached the size limit of the mouth opening, never produced strains in excess of 3000 pounds. As additional evidence that the frag-

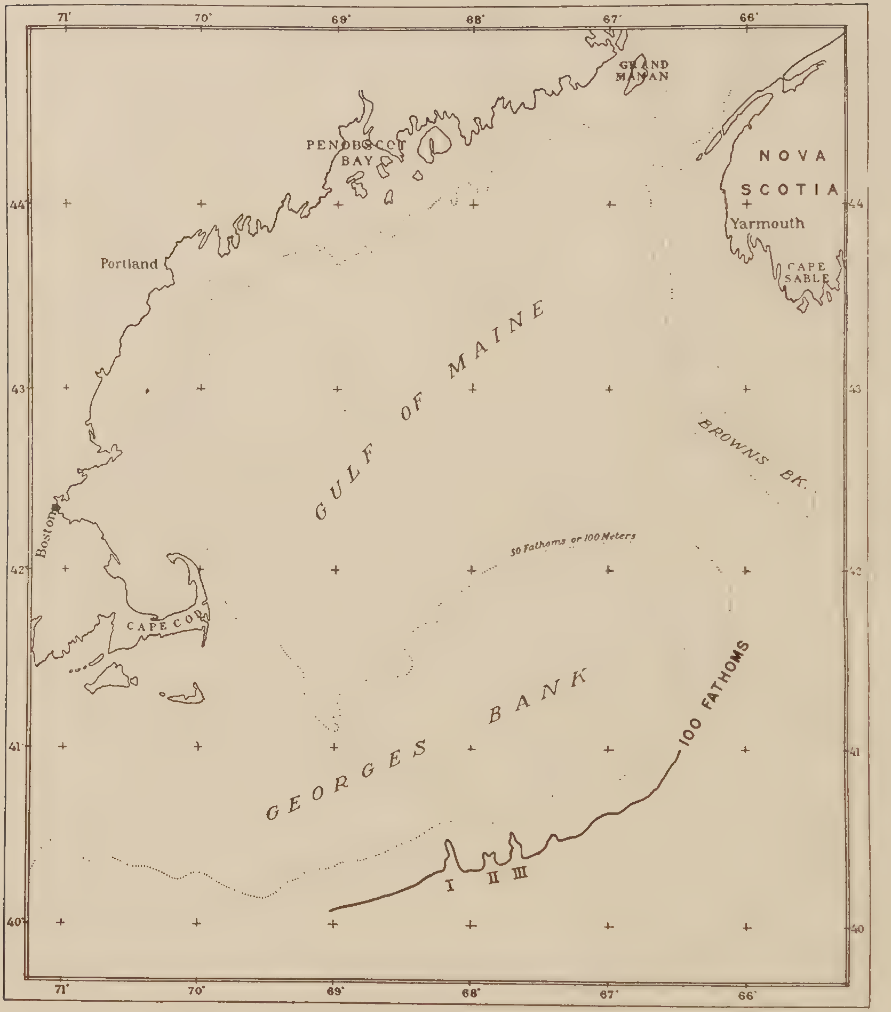


Figure 1.—*Position of Georges Bank and the three canyons*

ments were taken in place, freshly broken surfaces and weathered ones were usually found on the same specimen. In one instance, pieces weathered on all sides appeared in the tow with fragments of the same material showing freshly broken faces. The dredge obviously scooped up some of the talus at the base of the cliff before encountering the outcrop itself.

Tows were always made uphill, and, as the vessel was far ahead of the dredge, only the lower and the upper limits could be recorded. It is not possible, therefore, to fix the exact depth at which any single formation was encountered. The vertical range of each tow, however, was not great, and in no case amounted to more than 128 meters.

The middle and upper sections of the valleys, where the walls have the steeper gradients, yielded the best results. Here, the walls were either bare or the covering of Recent sediment was thin enough to allow the dredge to cut through. Toward their mouths the valleys begin to broaden, and the older rocks are blanketed with Recent material or glacial debris, too thick to be penetrated. The same holds true for the upper parts of the valley walls. Here, likewise, the gradient is less steep, and glacial debris has accumulated.

Several cores were taken with an instrument which consisted of a piece of 1½-inch brass pipe, having a union at one end and a T coupling for the attachment of the line, at the other. Around the union was cast 100 pounds of lead, and into it was screwed a 5-foot length of pipe of the same diameter, sharpened at one end. The tube was dropped with the winch running free, and considerable speed was attained as the weight of the wire gradually added to the weight of the tube. A check valve, to prevent the core from sliding out, was not needed in soft bottoms.

Georges Bank has a steep northern slope facing toward the Gulf of Maine. Although the gradient is not comparable to that of the canyon walls, it is considerably steeper than that of the Continental Slope. Consequently, it was thought worth while to repeat here the tactics employed in the canyons. The uphill tows were made between 68°48′ and 67°12′ W. Long., but in no case did the dredge encounter anything but Recent, unconsolidated material. Five cores were taken, but the contained foraminifera were all Recent forms. Probably because of the gentle slope, the older formations are effectively protected by the thick covering of present-day sedimentation.

MECHANICAL ANALYSIS

The combined sieve and hydrometer method devised by Arthur Casagrande, of the Harvard Engineering School, was used for the mechanical analysis of the sediments collected. As this has been described elsewhere, a detailed account is unnecessary here.[1] The principal errors formerly encountered in hydrometer technique have been eliminated by much experimental work. In dealing with marine samples, it is, of course, necessary to remove all traces of the electrolytes contained in sea water, before a complete separation can be made. Various methods have been used,[2] but repeated washings, the water being drawn off through Pasteur-

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[1] H. C. Stetson: *Scientific results of the Nautilus expedition, 1931,* Mass. Inst. Tech. and Woods Hole Oceanographic Inst., Papers in Physical Oceanography and Meteorology, vol. 2, no. 3, pt. 5 (1933) p. 17-19.

[2] Stina Gripenberg: *A study of the sediments of the North Baltic and adjoining seas,* Havsforskn. Inst. Skr., Helsingfors no. 96 (1934) p. 60-62.

Chamberland filters by means of a vacuum pump, were found to be thoroughly satisfactory in the case of the finer sediments. The last two or three washings should be made with distilled water. As chlorine is one of the commoner electrolytes in sea water, it was assumed that when all trace of it had been removed, no others were present. Minute amounts of the chlorides can easily be detected with silver nitrate.

Important textural features of the samples are represented according to the statistical method devised by Trask.[3]

Curves give an accurate picture of the individual characteristics of a sediment, but they are difficult to interpret in dealing with large numbers of samples. Histograms, though apparently easy to interpret, have so many inherent fallacies that their value is questionable.[4] Although something of the individuality of a sediment is sacrificed in the statistical treatment of the data, it is a system in which general relationships are easily and correctly grasped.

In Trask's system, the median diameter, an expression for sorting, and one for skewness are used. The first quartile, the median, and the third quartile diameters are taken from the cumulative curve and substituted in the two formulae.

"The median diameter indicates the mid-point of size distribution. One-half of the weight of the sediment is composed of particles larger in diameter than the median and one-half smaller."[5] This is the most important single constant.

The coefficient of sorting expresses the degree of sorting. It is based on a relationship of the first and the third quartiles. Twenty-five percent by weight of the sample is composed of grains of larger diameter than the first quartile, and seventy-five percent larger than the third quartile. It is derived from the formula $So = \frac{Q_1}{Q_3}$. Perfect sorting equals unity. The writer's experience with many samples indicates that a well-sorted sediment, such as a beach sand, has an average value for So of about 1.25, and a well-sorted, shallow-water sediment a value of about 1.46.

The coefficient of skewness measures dissymmetry of size distribution in relation to the median diameter. It shows on which side of the median diameter, and how far from it, the mode, or peak, of the distribution lies. It is derived from the formula: $Sk = \frac{Q_1 \times Q_3}{M^2}$. If Sk is greater than 1.0, or log *Sk* positive, the mode lies on the fine side of the median diameter. If *Sk* is less than 1.0, or log *Sk* negative, it lies on the coarse side; if *Sk* is 1, or log *Sk* 0, the mode corresponds with the median. The logarithm of *Sk* is given to bring out more clearly the relationship of skewness ratios, which may lie on either side of the median—*i. e.*, the amount of their divergence from it. The farther *Sk* diverges from 1.0, or log *Sk* from 0, the farther the position of maximum sorting lies from the median.

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[3] P. D. Trask: *Origin and environment of source sediments of petroleum* (1932) chap. 5. Houston.

[4] E. Wayne Galliher: *Cumulative curves and histograms*, Am. Jour. Sci., 5th ser., vol. 26, no. 155 (1933) p. 475-478.

W. C. Krumbein: *Size frequency distribution of sediments*, Jour. Sed. Petrol. vol. 4, no. 2 (1934) p. 68-70.

[5] P. D. Trask: *op. cit.*, p. 70.

In Table 1 are found the statistical constants just mentioned (p. 360). Table 2 lists each sample split into arbitrary size divisions, which are also read from the same cumulative curves (p. 361).

DESCRIPTIVE DATA

GENERAL STATEMENT

This section is concerned chiefly with the physical characteristics of the samples. Although the fossils naturally are included as part of the evidence under their respective tows and cores, they are merely cited here. A full account of the paleontology appears in the other divisions of this paper, under the respective authors.

CANYON I

In the westernmost canyon, which is designated Canyon I (Fig. 2), six successful tows were made and four cores were taken.

Tow 1 was made on the easterly side of the canyon, between 620 and 500 meters depth (N. Lat. 40°20′15″; W. Long. 68°06′30″). The bag came up full of unconsolidated green silt which contained nothing but Recent foraminifera, characteristic of the warm water beyond the continental margin. The strain on the wire was uniformly slight throughout the course of the tow, and no outcrops were encountered.

Tow 2 was made on the westerly side of the canyon (N. Lat. 40°20′15″; W. Long. 68°10′00″) between 256 and 164 meters depth. Angular pebbles obviously derived from glacial outwash were obtained. On the same side of the canyon, and in the immediate vicinity, two unsuccessful tows were made. In the first, between 292 and 200 meters depth, the dredge chattered along the bottom and hooked nothing. In the second instance, the dredge hung so hard that the safety rope broke, and only one small angular glacial pebble was recovered.

Only two types of sediment, both Recent, were encountered in the cores. The following description of each holds good for all other occurrences. For further data, the tables should be referred to.

Core 1 (N. Lat. 40°20′03″; W. Long. 68°08′00″) was taken in the center of the valley floor, at a depth of 943 meters, about midway between Tows 1 and 2. This core is 10 centimeters in length, with the upper

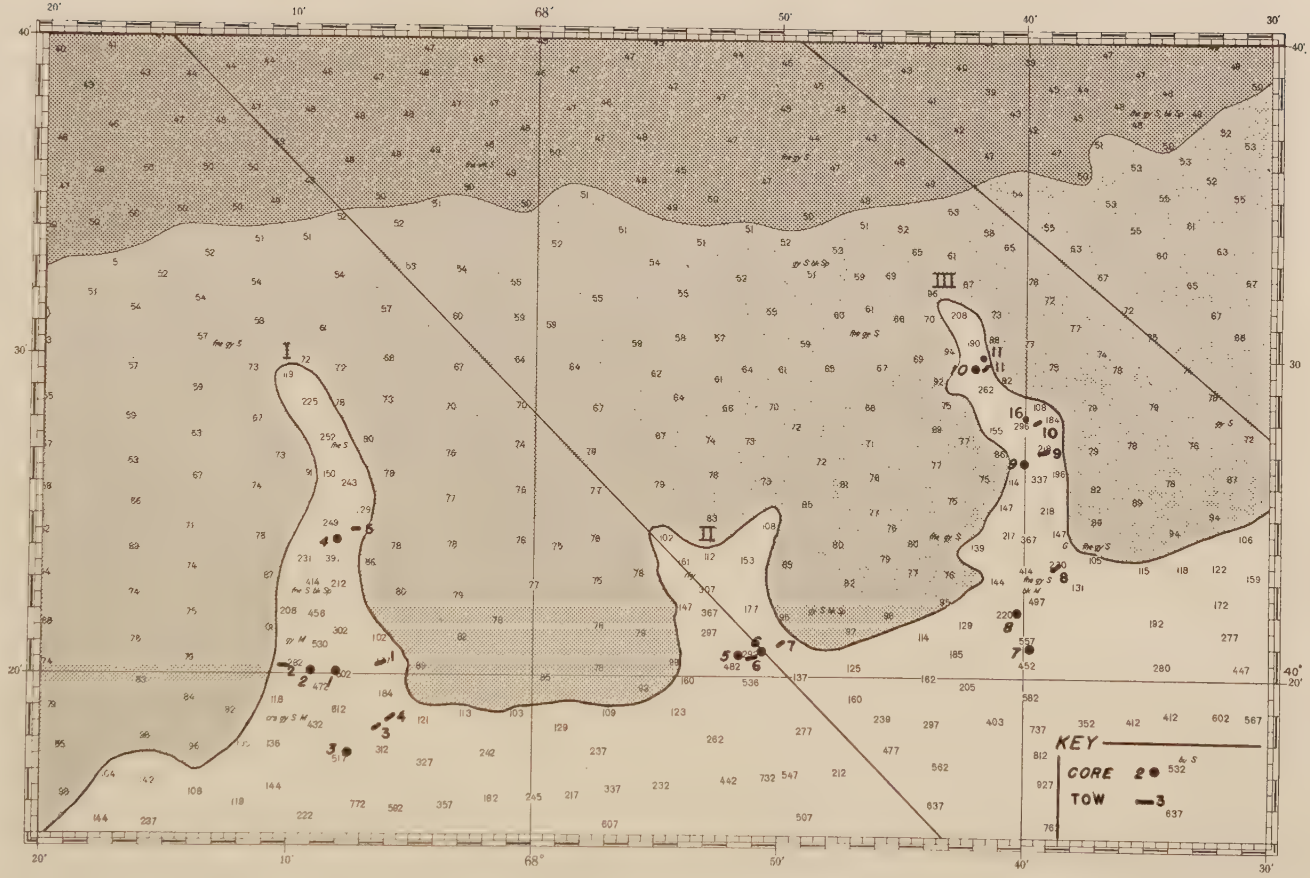

FIGURE 2.—*Western part of Georges Bank*

A portion of United States Coast and Geodetic Survey chart 3076, giving the positions of the dredging stations. Soundings in fathoms.

2 centimeters a greenish, sandy silt. The lower 8 centimeters is a compact, fine silt, pinkish in color. The difference in mechanical composition is well shown by the constants and size fractions. The top section has a median of .09 millimeter, and the two lower sections, a median of .006 millimeter. The sand percentage drops from 66.5 to 20.4 and 22.5, with a corresponding increase in silt, clay, and colloid in the two lower sections. The sandy silt has a fair sorting, with a large negative log *Sk*, indicating that the mode is far displaced from the median on the coarse side. The sorting of the fine silt divisions is very poor (7.8 and 11.3), though the negative log *Sk* is smaller. The foraminifera are Pleistocene to Recent throughout, but the assemblage from the finer sediment is a typically Arctic one, with species not now living in the surface sediments of this region. This poorly sorted, fine silt, with its characteristic fauna, was encountered at many places in the valley floors and walls. The sandy green silt at the top has the normal assemblage now living in the general vicinity.

Core 2 (N. Lat. 40°20′03″; W. Long. 68°09′00″), 633 meters depth, and 20 centimeters long, resembles Core 1 in that the Arctic assemblage is present in the lower 18.5 centimeters. Core 3 (N. Lat 40°17′30″; W. Long. 68°07′30″), 1030 meters depth, and Core 4 (N. Lat. 40°24′15″; W. Long. 68°08′00″), 593 meters depth, consist of Recent material throughout, as is shown by statistical constants and foraminifera.

Tows 3 and 4 were taken in N.Lat. 40°18′15″, W.Long. 68°06′30″ and N.Lat. 40°18′30″, W.Long. 68°05′55″, respectively. They were made on the easterly side of the canyon, and one is a continuation of the other. The depths were between 565 and 400 meters and between 400 and 290 meters. Angular glacial pebbles, with no evidence of rock outcrops, were obtained in each.

Tow 5 was made on the easterly side of the canyon, near the upper end (N. Lat. 40°24′30″; W.Long. 68°07′30″), between 596 and 480 meters depth. The tow yielded four types of material: a fairly well indurated sandstone, a hard green silt, small glacial erratics, and the unconsolidated green silt which has been regarded as the product of present-day sedimentation. The sandstone is coarse textured, very poorly sorted, and contains considerable silt. The quartz grains are angular and are held together by a calcareous cement. Glauconite and feldspar are the two next most important constituents, and the latter mineral has been almost completely kaolinized. Many fragments of this rock showed weathered surfaces on all sides and were obviously talus lying at the base of the cliff; other pieces showed freshly broken faces. From this sandstone, Stephenson has obtained a fauna which he assigns to the Upper Cretaceous. In terms of the New Jersey-Maryland section it would correspond to the upper part of the Matawan or the lower part of the Monmouth; and of the European section, Upper Campanian or Lower Maestrichtian.

The hard green silt, the second type of material obtained in this tow, crops out at three other localities. This deposit twice anchored the dredge firmly enough to check the ship's headway. It came up in large angular chunks, and was sufficiently compact and firm so that neither the washing it received on the trip to the surface, nor the strong compression in the dredge while towing, obliterated the freshly broken appearance of some of the faces. The borings of worms and other bottom-living organisms are perfectly preserved, which indicates a fair degree of consolidation in place. Present-day surface sediments could not undergo such handling and preserve these structures intact. So compact was this material that, on breaking some of the chunks open, the inner part was found to be almost dry. In Tows 6 and 9, pieces were brought up with weathered surfaces considerably stained and indurated by limonite, and extensively pitted and channeled by bottom-living organisms. These faces were directly exposed to the water and had no covering of any sort, as living seaweeds were found attached to them.

In Tow 5 the silt had a median diameter of .016 millimeter. The sorting is poor, 4.12, and a log *Sk* of —.38 indicates a very unsymmetrical curve with the mode of size distribution on the coarse side of the median. The same physical characteristics hold good for this material when encountered in Tows 6, 9, and 11. The unconsolidated silt and the small glacial erratics, likewise obtained in Tow 5, may have been picked up anywhere along the way, or they may possibly have formed a thin covering over the whole area through which the dredge penetrated.

Cushman considers that the foramineral fauna of this compact silt is definitely younger than Miocene and may be late Pliocene or even early Pleistocene. Many of the Recent forms present in the cores and the surface sediments of the region are not found in the silt, and there are several forms ranging back into the late Tertiary, which, though present in the silt, are absent in present-day sediment. The fact that certain late Tertiary forms which are living today are found in both the silt and the sediment does not invalidate Cushman's supposition. The genus *Plectofrondicularia* is present; some species are related to species which are good index fossils to the late Tertiary of California, but, as the forms here are new species, it cannot be assumed as yet that their ranges are similarly restricted. The assemblage, taken as a whole, seems to indicate a deep-water environment. About such an assemblage very little is known, as the Tertiary fauna of the Atlantic Coastal Plain is a shallow-water one. The silts from Tows 6 and 11 yielded some shells which Stearns MacNeil, of the United States Geological Survey, has identified as *Macoma* cf.

calcarea Gmelin. He states, in a personal communication, that "this is a species belonging to northern waters and is not known in beds older than Pleistocene." It is possible, however, that this species has a greater geologic range than is known, as *Macoma balthica* Linné, a closely related species is found in the Red Crag (Pliocene) of Norwich, England. In general, it may be said at present that the fauna cannot be older than Miocene, and that the indications favor late Tertiary.

CANYON II

From the middle canyon, designated Canyon No. II, two tows were taken, one directly uphill from the other, and also two cores, one at the beginning of the first tow and one between the tows (Fig. 2).

Core 5 (N.Lat. 40°20′40″; W.Long. 67°51′30″) 864 meters depth, and Core 6 (N.Lat. 40°20′40″; W.Long. 67°50′40″) 530 meters depth, both penetrate the coarser surface silt and reach the finer-grained silt containing the Arctic fauna, going respectively 60 centimeters and 94 centimeters below the surface of the bottom.

Tow 6 (N.Lat. 40°20′40″; W.Long. 67°51′15″) was made on the easterly side of the canyon, between 600 and 530 meters depth. Four types of material were obtained: a friable glauconitic sandstone, the compact green silt, small glacial erratics, and unconsolidated silt.

The glauconitic sandstone came up in fragments which are fairly friable. It is impure, quartz sand being the dominant constituent, mixed with considerable proportion of silt. The quartz sand is very poorly sorted; the larger grains have a fair degree of rounding and are somewhat frosted. The foraminiferal fauna of this sediment is the equivalent of that found in the Navarro formation of Texas. The compact, green silt has already been described under Tow 5. In this particular case, the grains are a little finer than in the other instances, having a median diameter of .009 millimeter, with a correspondingly poorer coefficient of sorting of 5.45. The foraminifera, however, are the same as those found in the compact green silts from Tows 11 and 5, and the same *Macoma* found in Tow 5 is present.

Tow 7 (N. Lat. 40°21′00″; W. Long. 67°50′00″) was made uphill from Tow 6, and between 512 and 320 meters depth. Only glacial erratics and Recent, unconsolidated green silt were obtained.

CANYON III

From the easternmost canyon, designated Canyon No. III, four tows and six cores were taken.

Tow 8 (N.Lat. 40°23′30″; W.Long. 67°39′00″) was made in waters between 475 and 302 meters in depth, half way up the easterly side of the canyon. Only angular glacial pebbles and Recent unconsolidated material were obtained.

Tow 9 (N.Lat. 40°27′00″; W.Long. 67°39′30″) was made on the easterly side of the canyon, between 640 and 512 meters depth. From it was obtained an impure glauconitic greensand with a large admixture of quartz, the consolidated green silt, and the Recent, unconsolidated green silt. The foraminifera from this greensand constitute a warm-water fauna not older than late Pliocene, and are representative of conditions which existed along this coast prior to the lowered temperature of the Pleistocene.

The consolidated green silt is here a little coarser than in the other tows. having a median diameter of .029 millimeter. The sorting is similar to the other Recent cores, and percentages in the size fractions are comparable except for an increase in the sand division at the expense of the silt. As was the case with the other three outcrops, the material came up in large fragments, sufficiently compacted to be almost dry inside, and to retain the burrows of worms and other bottom feeders. The foraminifera represent the same "late Tertiary" assemblage as that already described.

Tow 10 (N.Lat. 40°28′00″; W.Long. 67°39′25″) was taken between 492 and 412 meters depth. It yielded a large amount of angular, well-sorted glacial pebbles and unconsolidated Recent sediment.

Tow 11 (N.Lat. 40°29′45″; W.Long. 67°41′45″) was taken between 458 and 452 meters depth. The tow was begun at the place where Core 10 was taken, and the dredge anchored itself almost at once. Two types of material were obtained—the compact, green silt mentioned in three other instances, and Recent, unconsolidated material.

Core 7 (N.Lat. 40°20′50″; W.Long. 67°39′50″) 1057 meters depth; Core 8 (N.Lat. 40°22′00″; W.Long. 67°40′15″) 612 meters depth; Core 9 (N.Lat. 40°26′45″; W.Long. 67°40′00″) 596 meters depth; Core 10 (N.Lat. 40°29′45″; W.Long. 67°41′47″) 458 meters depth; and Core 11 (N.Lat. 40°29′45″; W.Long. 67°41′40″) 396 meters depth, all fail to penetrate the coarse surface silt. The foraminifera of Cores 10 and 11 are Gulf Stream forms.

NORTH SLOPE

Two sections of the steep north slope, about 20 miles apart, were sampled in the hope that the tactics employed in the canyons would yield similar results. Two tows and four cores were taken, but only Recent unconsolidated material was obtained. There was no trace of any of the older formations encountered in the canyons, nor even of the fine silt with the Arctic foraminifera.

The first traverse began at N. Lat. 42°04′00″, W. Long. 66°48′00″ in 11 meters of water and ran northwest to N. Lat. 42°16′30″, W. Long. 66°51′30″ to a depth of 267 meters. The second traverse began at N. Lat. 42°04′00″, W. Long. 67°05′00″, in 10 meters of water, and ran down the slope in a northwesterly direction to N. Lat. 42°16′30″, W. Long.

67°10′30″, to a depth of 267 meters. These traverses began in sand obviously under the influence of wave action on the top of the bank, and reached silts characteristic of the deeper parts of the Gulf of Maine basin. The silts were picked up at about 200 meters depth. As the details of these traverses do not especially concern the problem at hand, they have been omitted from the tables.

CONFIGURATION AND ORIGIN OF THE CANYONS

It is not the purpose of this study to enter into the controversy concerning sub-aerial versus submarine origin of canyons. Its chief concern is the dating, and the description of the sediments composing the walls. The question of the origin is still an open one, and the data are not yet at hand which will warrant a complete rejection of either view.

It is only very recently that submarine currents have received any serious support, and their chief advocate[6] would be the last to claim that as yet his proposals constitute more than a working hypothesis. Nor can one discard entirely the older view, that the valleys are stream cut. They have certain characteristics which demand attention and cannot be ignored in spite of the seemingly insurmountable difficulties in the way of orogenic movement, or a eustatic shift of sea level of sufficient magnitude to produce them. It is pertinent, therefore, to review the arguments for a sub-aerial origin, both to point out certain factors which appear to have passed unnoticed, and to further emphasize the fact that there are many problems involved which still await a satisfactory solution.

F. P. Shepard[7] has been the chief advocate of a fluviatile origin. The soundings are numerous enough to enable him to draw contour maps of considerable accuracy, and to obtain a good picture of the physical characteristics of the valleys. They are narrow; they are incised only a short distance into the shelf; and their head and side walls are steep. In cross-section they are V-shaped. Their courses are sinuous, and their bottoms slope outward practically continuously. Headward extensions across the shelf are unknown in these east coast canyons, except in the case of the Hudson.

There has been considerable speculation as to the drainage systems of which these canyons may be the remnant, as many have assumed that they must once have had a greater headward extension than they now possess. Spencer[8] made an attempt to connect a few of them with present-day rivers. Had such large streams, draining the hinterland, crossed the relatively soft sediments of the shelf, they might have been expected to cut deep, graded channels. The absence of such features demands an explanation. Assuming that such channels did exist, they could only have been obliterated by marine planation and fill, following subsidence. In favor of this theory, there is a rather general uniformity of the depth of the break in slope for all the shelves of the world, as has been pointed out by Shepard.[9] In other words, stillstand at present sea level is supposed to have continued long enough to produce uniformity of grading. This would inevitably result in much sediment, which would fill the canyons. Consequently, Shepard postulated submarine landslides to clear them out occasionally.

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[6] R. A. Daly: *Origin of submarine "canyons"* (Abstract), Geol. Soc. Am., Pr., 1935 (1936) in press.

[7] F. P. Shepard: *Canyons off the New England Coast,* Am. Jour. Sci., 5th ser., vol. 27, (1934) p. 24-36.

[8] J. W. Spencer: *Submarine valleys off the American coast and the North Atlantic,* Geol. Soc. Am., Bull., vol. 14 (1903) p. 207-226.

There are, however, several factors which cast a certain amount of doubt on the assumption that these canyons are remnants of larger valleys or that these master streams ever possessed graded valleys across the shelf.

Take the case of the Hudson. There a broad shallow trough leads out of the mouth of the river and crosses the shelf, where it becomes a deep, narrow gorge at the break in slope. The outer gorge is obviously different from the canyons of Georges Bank and those off the Maryland and Delaware coasts, even if allowance be made for the fact that it has not been surveyed in comparable detail. The depth, and the steepness of the side walls are about the same, but the course of the gorge is a pronounced S-curve instead of being nearly straight. As might be expected, the headwall is not very abrupt, and it has been cut back into the continental platform about twice as far (20 odd miles) as any of the others. The shallow portion begins just south of Ambrose Lightship, in about 38.5 meters of water, and gradually slopes to the 50-fathom curve (about 91.5 meters) 76 miles seaward. Its depths below the surface of the shelf varies from about 14 to 27 meters. At the 50-fathom curve the channel descends abruptly to 380 meters below sea level, deepening to 870 meters 20 miles away. It lies from 250 to more than 700 meters below the surface of the outer part of the shelf. How such a condition could have arisen had the valley been well graded up to the river mouth is difficult to imagine. Marine planation could hardly have resulted in such unequal filling in a channel cut in a nearly level platform.

If one postulates straight uplift of the continental margin, with no tilting, or a eustatic shift of sea level, a stream from the hinterland, flowing across the nearly level surface of the shelf, would deposit part of its load on its floodplain and do little cutting. On reaching the change of gradient at the break slope, it would cascade into the ocean. From this point seaward, deep trenching would be initiated, and the headwall would

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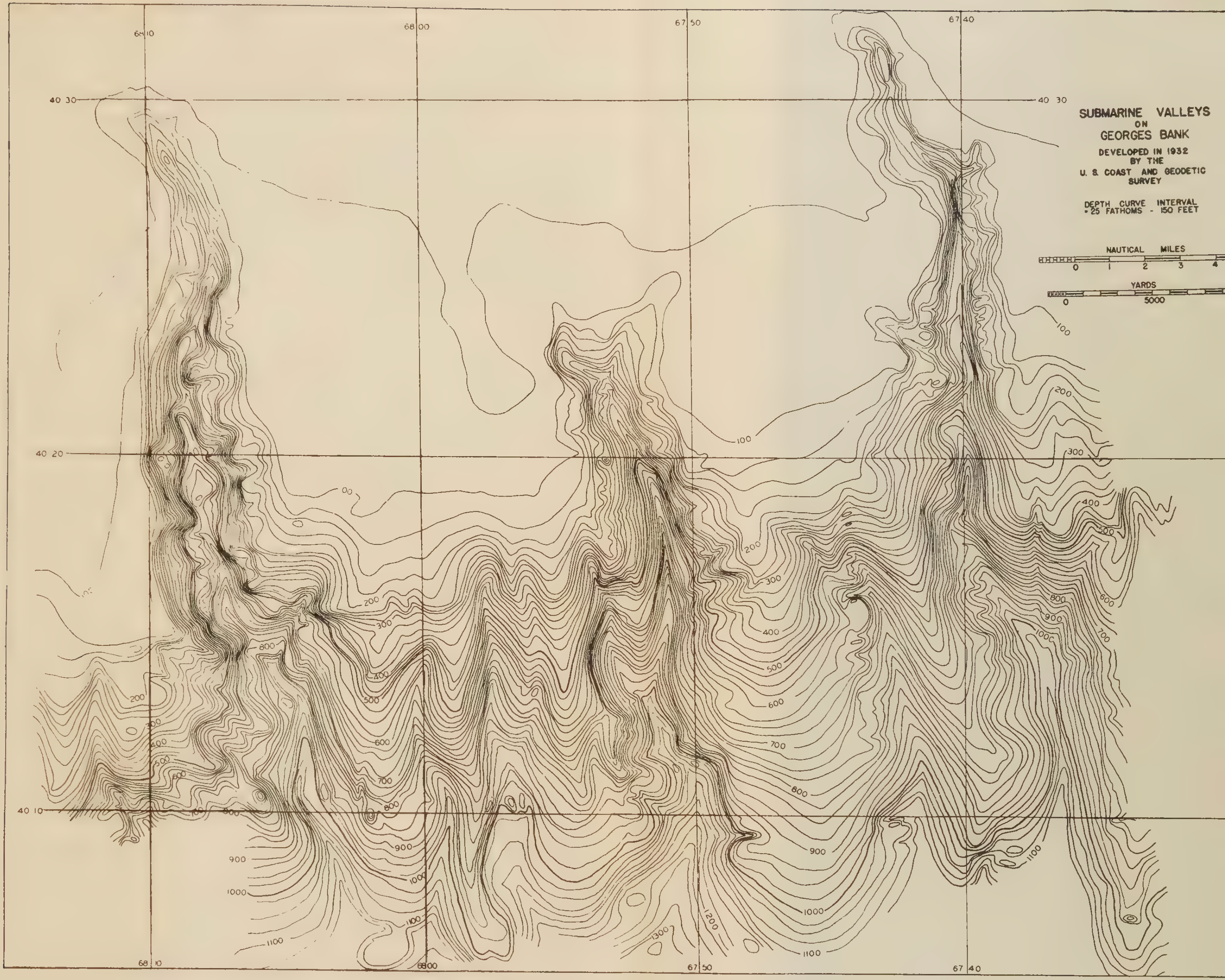
[9] F. P. Shepard: *op. cit.*



CONTOUR MAP OF THE THREE CANYONS

Drawn by F. P. Shepard from data furnished by the United States Coast and Geodetic Survey. Depth of curve, 25 fathoms.

gradually work inland by headward erosion, after the manner of the Niagara gorge. There would be no deep graded channel across the shelf until the falls had completely crossed it. The Hudson fulfills the conditions presented here to a remarkable degree.

In the case of Georges Bank, the abundance of the canyons themselves precludes the possibility that they are all caused by streams crossing the shelf. Upward of forty large ones are found on the southern face, in addition to many minor ones. So closely spaced and so similar in size are they that it is difficult to conceive that the necessary number of rivers flowing out of a hinterland could have existed side by side, even before the existence of the Gulf of Maine. Stream piracy would certainly have enlarged certain ones at the expense of the others.

The writer is indebted to Kirk Bryan for a suggestion which might explain this situation. It is not necessary to appeal to some ancient river, with its headwaters in the hinterland, to provide the means for cutting these canyons. In a plateau country, starting upon the face of a scarp, canyons of the order of magnitude represented here can grow by headward erosion through the agency of groundwater sapping. Many formed by this means are well shown on the United States Geological Survey's topographic sheet of the Bright Angel quadrangle, Coconino County, Arizona. A portion of this sheet, in which the similarity of the canyons to those on Georges Bank is particularly striking, is reproduced in Plate 2.

The Transept, a side valley off Bright Angel Canyon, is very similar in size, depth, and configuration to Canyon II of this paper (Pl. 3). The head of Bright Angel Canyon itself is more like Canyons I and III.

The same conditions on a smaller scale are well illustrated by a scarp near Cameron, Arizona (Pl. 1, fig. 2). Elevation of the continental margin would provide ideal conditions for erosion of this sort. If Georges Bank now stood about 7000 feet above sea level, its southern face would look not unlike the scarp near Cameron.

It has been suggested that the valleys are due to faulting.[10] However, the straight walls and trough-like shape characteristic of such features are lacking. As Shepard[11] points out, "it is usual to find horsts or step faults rather than the accordant plateau levels that are found on the sides of most submarine valleys."

Submarine currents, likewise, have been considered as agents. It is difficult to conceive of density currents, due to differences in temperature and salinity, powerful enough to cut such gorges. If, however, such a current could be produced, it would be equally difficult to imagine it flowing at right angles to the coast line, or to find it restricted to such limited areas. Another objection to this mode of origin is the fact that the valley bottoms are filled with fine-grained sediments, thereby precluding the possibility that such a current is flowing at the present time. It is not reasonable to suppose that the currents everywhere would have cut to a similar depth and then suddenly have become inoperative. Submarine currents of this type, as agents, are forces whose existence has never been demonstrated. The conditions necessary to produce them are completely out of line with known hydrographic conditions, as is shown by the data that are being accumulated by modern work in physical oceanography.[12]

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[10] A. C. Lawson: *The geology of Carmelo Bay*, Calif. Univ., Dept. Geol., Bull. 1 (1893-1896) p. 1-59.

[11] F. P. Shepard: *Submarine valleys*, Geog. Rev., vol. 23 (1933) p. 79-98.

The foregoing criticism does not apply to a theory recently put forward by Daly,[13] who appeals to a different type of density current to accomplish the work. His differential densities are obtained by bringing large quantities of mud into suspension, by wave agitation. According to his theory, such a situation must have arisen during the lowered sea level of Pleistocene times, when large areas of soft deposits, formerly below wave base, were brought within the reach of wave scour. This heavy water would first seek the lowest depressions on the shelf, such as might be caused by initial irregularities. It would run down them and, eventually, would flow over the steeper gradient of the continental slope, with greatly accelerated motion, thereby cutting the canyons. Numerous factors remain to be evaluated; such as, the amount of energy available for the work, the relative hardness of the sediments to be cut, and the effect of the lighter less-saline water near shore. It is a mechanism, which, given the proper conditions, could be made to work. Daly himself says he does not in any sense regard it as a proven theory, but, rather, as a working hypothesis put forward to circumvent the seemingly insurmountable obstacles of continental uplift or eustatic shift of sea level.

INTERPRETATION OF DATA

The data with regard to the relationships of the different sediments to each other, may now be examined and the probable conditions which exist in these valleys today may be reconstructed. The simple cases will be taken first. Figure 3 shows the relationships of the tows, in graphic form.

Material obviously glacial in origin (i.e., angular pebbles and small boulders) and Recent silt were the only constituents of every tow, from a depth of 450 meters to the canyon's rim. Glacial material was found in only two instances below this depth—Tow 6, reaching 530 meters, and

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[12] C. Iselin: *Personal communication.*

[13] R. A. Daly: *op. cit.*

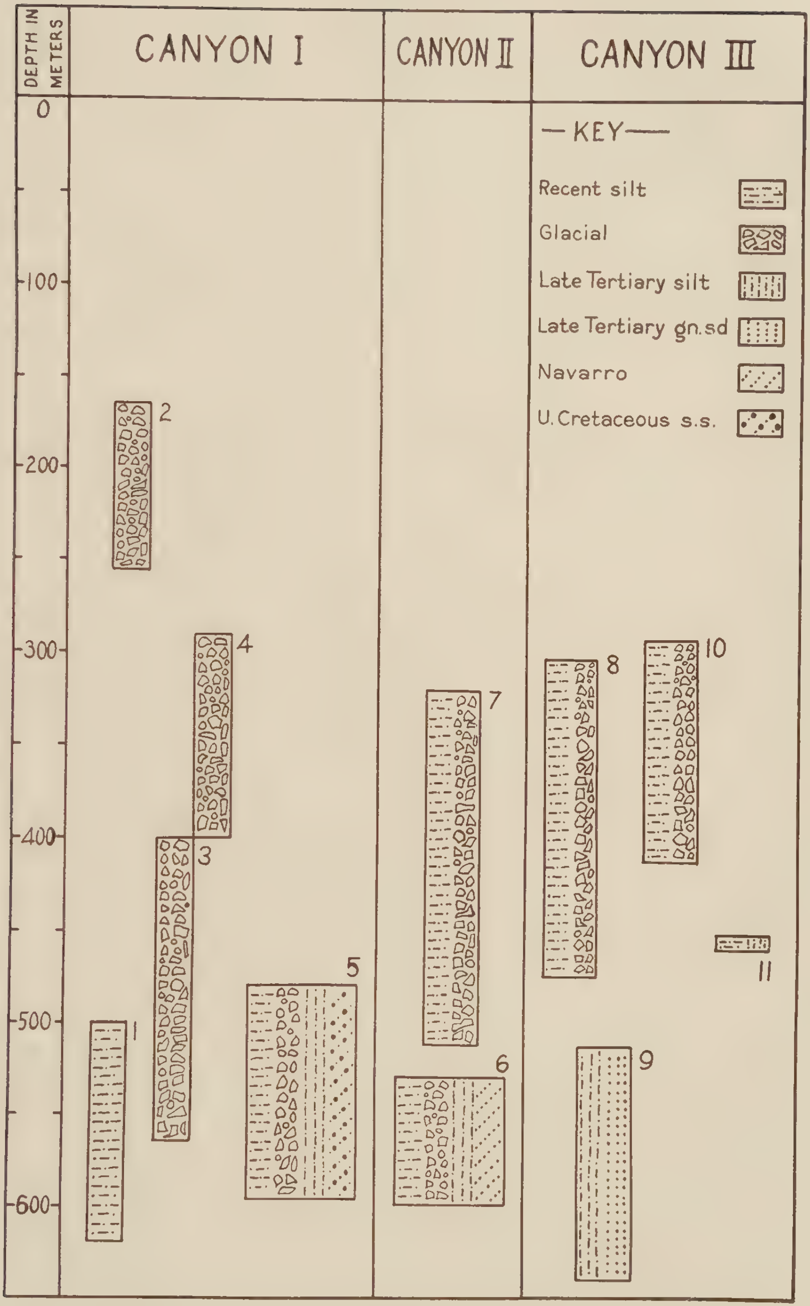

FIGURE 3.—*Vertical extent of the tows on the canyon walls*

Tow 5, 480 meters. Tows 3, 7, 8, containing glacial erratics, start below 450 meters but extend well above that depth, so that there was ample opportunity for the angular pebbles to have been picked up by the dredge toward the end of the tow. Tow 3 ends at 400 meters, Tow 7 at 320, and Tow 8 at 302 meters. It is not necessary to consider the landslide hypothesis to explain the fact that glacial material is not found everywhere. Unconsolidated material could accumulate at any place where the gradient of the valley walls is sufficiently gentle to permit it. The best places are the valley floors and the upper slopes. Doubtless the floors are mantled with a veneer of glacial debris, but, as these are quiet places, fine-grained sediments would later accumulate, and they have probably buried the glacial material. Tow 1 and the several cores indicate that such a deposit has been formed. The upper slopes, being nearer the surface, are places of greater turbulence; hence, the finer material could not accumulate, or the layer was thin enough to allow the dredge to cut through it.

Certain cores—namely, numbers 1, 2, 5, 6, and 8, all taken below 530 meters—show a fine-grained silt in the lower sections. This contains modern Arctic foraminifera, but species that are not found in this region at present. The upper sections have the fauna normal for this part of the coast. The contact between the two types of material is plainly visible, and important textural differences were brought out by the mechanical analysis (Tables 1 and 2). The older sediment, finer grained than usual for the present day bottoms of the region at similar depths, was probably accumulated during the melting of the Pleistocene ice. Material of this type would naturally be deposited in the quieter and deeper parts of the valleys, just as the Pleistocene silts and clays, now above sea level, were laid down in estuaries and in ponds and lakes. The silt, doubtless, overlies all the valley floors, but only where the cover of present-day material is relatively thin is one able to reach it. Present-day sediments in the valleys consist of sandy, green silt, the characteristics of which are given in the data for the uppermost sections of all the cores. Smears of it came up in most of the tows, but, even if the dredge were cutting through a layer of it to older rocks below, the large mesh of the bag would allow most of it to wash through.

The relationships of the three types of sediments to each other, and their positions in the valleys, are clear. Now comes the critical point in the discussion. Much depends on the correct answer to the question: Are the Upper Cretaceous and the late Tertiary rocks, obtained from the walls of the canyons, actually strata truncated by stream erosion, or are they fill in older channels? Whichever proves to be the case, there can be no question but that the fossiliferous rock was found in place.

Following up the landslide hypothesis, Shepard (personal communication) has suggested the possibility that the dredge might have encountered the "remnants of a former filling left sticking to the walls, the rest having slid out and down the canyon floor."

Cretaceous or Tertiary fill in an older cut would be distributed after the manner of the glacial and Recent fill in the present-day valleys. It would mantle all slopes that were gentle enough to allow it to stick, and would tend to conform to the topography of the valley, which is exactly what does happen.

With these suggestions in mind, one is in position to summarize the data obtained in the four critical tows. Figure 3 should again be referred to.

Tow 5, Canyon I, picked up Upper Cretaceous sandstone (Upper Monmouth or Lower Matawan), Tertiary silt, small glacial erratics, and present-day silt between 596 and 480 meters depth, in about .3 nautical miles of travel. It started from the valley bottom and was preceded by a core, 40.5 centimeters long, consisting of Recent material throughout. Again, in about .3 nautical miles, Tow 6, Canyon II, picked up upper Cretaceous sandstone (Navarro), Tertiary silt, and Recent silt, traveling from a depth of 600 to 530 meters, but starting about 287 meters above the valley floor. Core 5, 67.5 centimeters long, was taken practically on the valley floor, in 864 meters depth, before the tow started, and Core 6, 91 centimeters long, immediately after the tow ended. Each had 7 to 8 centimeters of the cold-water silt at the bottom, but the rest was present-day accumulation.

Tow 7 began only 18 meters farther up the slope than the upper limit of Tow 6, and in the same traverse, yet only glacial erratics and Recent silt were obtained in more than .3 nautical miles of towing. Tow 9, Canyon III, encountered Tertiary silt and greensand between 640 and 512 meters depth, traveling less than .3 miles. A core, 15 centimeters long, which was taken just before the tow was started, contained only Recent material. Tow 11 anchored the ship almost immediately, traveling only 6 meters vertically (458 meters to 452 meters depth). Tertiary silt was obtained. A core, 49 centimeters long, taken just before the dredge was lowered, contained only Recent material.

The fact that four tows at about the same depth yielded something besides Recent silt and glacial erratics is significant. The width of this zone is only 188 meters, as fixed by the extreme upper and lower limits of these tows. The contact between the Upper Cretaceous and the Tertiary lies, therefore, somewhere between 600 and 480 meters below present sea level. It was picked up on two vertically overlapping tows in different canyons, the maximum upper and lower limits of which are only 120 meters apart. This range could, doubtless, be still further narrowed were it possible to employ more precise field methods. The fairly restricted distribution of this fossiliferous material is an argument against its deposition as sheets of valley fill. More recent sediments, which are actually valley fill, are found at almost all levels within the valleys. On the other hand, the situation is just what one would expect if the fragments in question were broken from nearly flat-lying sediments, deposited like those of the existing Coastal Plain, and then truncated by stream erosion.

These critical tows occupy about the same relative position in the valley cross-section. They are situated neither in the valley bottoms nor on the gentle upper slopes, but a short distance above the valley floor. An examination of the original sounding data shows that the steepest gradients are found here—i.e., in the middle and upper parts of each canyon. It is also interesting to note that these four tows were made in areas in which the contours on Shepard's map show close crowding (Pl. 3). Slight discrepancies in location are easily within the normal limits of a ship's real and plotted positions. Slopes above 30 to 35 degrees probably would not allow sediment of any sort to collect on them, and this would certainly be true for any cliff. The consolidated material obtained in Tows 6 and 9 is at present exposed to the water, and has no cover of unconsolidated sediment. If cliffs do exist in the valleys, the places where these four tows were taken would be among the most likely locations.

In the case of Georges Bank, it is difficult to deduce what the stratigraphy at the continental margin should be. The Cretaceous and the Tertiary disappear beneath the sea, a hundred or more miles to the west. The contact between the Coastal Plain sediments and the crystalline basement lies hidden beneath the Gulf of Maine. South of New York the situation is much simpler, and one is able, with a fair degree of certainty, to deduce from the known structure what the material should be in which the southern canyons are cut.

The strata of the Coastal Plain form a wedge of nearly flat-lying sediments, with the thin edge at the Fall Line, dipping gently seaward, and thickening in the same direction. They rest unconformably on a pre-Cretaceous surface of crystalline and metamorphic rocks, which physiographers term the Fall Line peneplain.[14] Well borings through the Coastal Plain sediments show that this basement has everywhere a seaward slope,[15] and, when the depths at which it is reached in these borings is plotted, the data indicate that it is a "fairly close approximation to a plain surface."[16] In Maryland and New Jersey the average seaward slope of this surface is 42½ to 50 feet per mile.[17] At Atlantic City the Coastal Plain wedge (post-Jurassic) has a thickness of more than 2306 feet, for a well drilled to that depth, 1,000 feet from shore, failed to reach the basement.[18] Three wells at Crisfield, Maryland—1018, 1033, and 1040 feet, respectively—also failed to penetrate the sedimentary cover.[19] Yet, 50 to 70 miles off the New Jersey–Maryland shore the canyon rims are cut in materials which lie only 300 to 600 feet below present sea level. There are only two possible hypotheses as to what these materials may be: (1) the crystalline basement, and (2) the thick seaward portion of the Coastal Plain wedge. To warp up the basement from a depth of over 2300 feet at the line where the sedimentary rocks dip beneath the sea to the depth at which they could serve as canyon walls, implies a complete reversal of the structural trends which hold constant from New Jersey to the Gulf Coast. The natural assumption would be that structural conditions, as now known ashore, hold good for the whole continental shelf, and that the Coastal Plain wedge continues to thicken above the seaward-tilted crystallines and metamorphics, eventually forming at least the upper part of the continental slope at the continental margin. Such being the case, sediments corresponding in age to those taken from the Georges Bank Canyons might be expected to form the actual walls of the southern canyons, and it would naturally be assumed that the material was obtained from the walls themselves and not merely from the fill of older cuts.

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[14] W. Johnson: *Stream sculpture on the Atlantic slope* (1931) p. 5-11. New York.

[15] N. H. Darton: *Artesian well prospects*, U. S. Geol. Surv., Bull. 138 (1896).

Physiographic evidence makes it clear that whatever origin is attributed to one valley must be applicable to all, and the correspondence in depth makes it most probable that all the cutting took place at the same time. At the present writing, surveys as detailed as those carried out on Georges Bank have been made of three canyons to the south. One lies somewhat north of the mouth of the Chesapeake, and two are off the Maryland-New Jersey coast. Several others, vaguely indicated on the charts, as far south as Cape Hatteras, will undoubtedly prove to be of the same type, but the present soundings are too sparse to permit any definite conclusions about them. The three best charted southern valleys have the same general configuration and depth as those of Georges Bank, and all are cut back into the edge of the shelf to approximately the same distance. The detailed

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[16] G. T. Renner: *Physiographic interpretation of the Fall Line peneplain*, Geog. Rev., vol. 17 (1927) p. 278-286.

[17] N. H. Darton: *op. cit.*, p. 281.

[18] D. G. Thompson: *Ground water supplies of the Atlantic City region, New Jersey.* Dept. Conservation and Development, Rept., Bull. 30 (1928) p. 27.

[19] N. H. Darton: *op. cit.*, p. 128.

Table 1.—*Statistical constants*

Sample	Depth below top of core (cms.)	Millimeters			*So*	Log *Sk*
		Q_1	Median	Q_3		
		CANYON I				
Core 1						
Sec. 1	0–2	.145	.092	.0105	3.72	−.75
Sec. 2	2–6	.037	.0064	.0006	7.85	−.27
Sec. 3	6–10	.046	.0062	.00036	11.30	−.37
Core 2						
Sec. 1	0–1.5	.056	.0092	.0027	4.56	.25
Sec. 2	6-10.5	.021	.0043	.00044	6.91	−.30
Sec. 3	10.5–15	.044	.0048	.00052	9.20	.00
Sec. 4	15–20	.0285	.0043	.00012	15.40	−.73
Core 3						
Sec. 1	0–4	.086	.084	.032	1.64	−.41
Sec. 2	25–29	.090	.084	.048	1.37	−.21
Sec. 3	41.5–45.5	.105	.078	.0195	2.32	−.47
Sec. 4	58.5–62.5	.088	.077	.014	2.50	−.68
Core 4						
Sec. 1	0–4	.087	.047	.0056	3.94	−.66
Sec. 2	16–20	.094	.064	.025	1.94	−.24
Sec. 3	36.4–40.5	.120	.060	.019	2.52	−.20
Tow 5	....	.0425	.016	.0025	4.12	−.38
		CANYON II				
Core 5						
Sec. 1	0–4	.170	.137	.080	1.46	−.14
Sec. 2	17.5–21.5	.094	.064	.025	1.94	−.24
Sec. 3	35–39	.110	.068	.021	2.29	−.29
Sec. 4	51-55	.042	.0135	.0019	4.70	−.36
Sec. 5	63–67.5	.060	.0091	.0011	7.31	−.09
Core 6						
Sec. 1	0–4	.205	.128	.086	1.54	.03
Sec. 2	27–31	.460	.210	.115	1.99	.20
Sec. 3	40.5–44.5	.423	.193	.095	2.11	.03
Sec. 4	57.5–61.5	.210	.110	.018	3.42	−.50
Sec. 5	74–78	.082	.011	.0017	6.95	.06
Sec. 6	94.5–99	.070	.0078	.0011	7.98	.10
Tow 6	....	.0436	.0090	.00147	5.45	−.10
		CANYON III				
Core 7						
Sec. 1	0–4	.209	.081	.030	2.64	−.02
Sec. 2	27.5–31.5	.070	.027	.0032	4.68	−.51
Sec. 3	56–60	.051	.016	.0025	4.51	−.30
Sec. 4	78–82	.036	.0088	.0024	3.88	.05
Sec. 5	93.5–97.5	.032	.0088	.0013	4.96	−.27
Sec. 6	112–116	.081	.012	.0016	7.11	−.05
Core 8						
Sec. 1	0–4	.098	.088	.033	1.72	−.38
Sec. 2	28.5–32.5	.188	.088	.027	2.09	−.39
Sec. 3	54–58	.088	.074	.011	2.83	−.75
Sec. 4	79–83.5	.100	.062	.0092	3.30	−.62
Core 9						
Sec. 1	0–4	.220	.185	.150	1.21	−.02
Sec. 2	18.5–22.5	.230	.180	.135	1.30	−.02
Sec. 3	37–41	.180	.155	.110	1.28	−.08
Sec. 4	50–53.5	.190	.160	.102	1.36	−.12
Core 10						
Sec. 1	0–4	.190	.130	.076	1.58	−.07
Sec. 2	22.5–26.5	.180	.135	.078	1.52	−.11
Sec. 3	45–49	.185	.145	.100	1.36	−.06
Core 11						
Sec. 1	0–5	.195	.130	.086	1.51	.00
Sec. 2	10.5–15	.130	.103	.064	1.42	−.11
Tow 9	....	.066	.0294	.0037	4.22	−.55
Tow 11	....	.039	.0134	.0023	4.11	−.30

Table 2.—*Size fractions, based on percentage of total weight*

Sample	Depth below top of core (cms.)	Gravel (1–30 mm.)	Sand (.05–1 mm.)	Silt (.005–.05 mm.)	Clay (.001–.005 mm.)	Colloid (0–.001 mm.)
CANYON I						
Core 1						
Sec. 1	0–2	0.0	66.5	13.2	7.0	13.3
Sec. 2	2–6	0.0	20.4	32.6	17.0	30.0
Sec. 3	6–10	0.5	22.5	28.9	14.3	33.8
Core 2						
Sec. 1	0–1.5	2.2	24.8	31.5	41.5	0.0
Sec. 2	6–10.5	0.0	10.5	37.5	20.0	32.0
Sec. 3	10.5–15	0.0	13.0	36.2	18.8	32.0
Sec. 4	15–20	0.0	13.9	34.4	15.2	36.5
Core 3						
Sec. 1	0–4	0.0	71.0	17.3	7.7	4.0
Sec. 2	25–29	0.0	74.7	17.3	4.0	4.0
Sec. 3	41.5–45.5	0.0	63.3	22.7	7.0	7.0
Sec. 4	58.5–62.5	0.0	64.6	19.4	10.0	6.0
Core 4						
Sec. 1	0–4	0.6	47.4	29.3	21.7	1.0
Sec. 2	16–20	0.0	63.6	22.4	7.0	7.0
Sec. 3	36.5–40.5	0.0	57.0	27.8	9.2	6.0
Tow 5	....	0.0	20.0	48.0	14.0	18.0
CANYON II						
Core 5						
Sec. 1	0–4	3.0	80.2	10.8	4.0	2.0
Sec. 2	17.5–21.5	0.0	60.2	26.8	7.1	5.9
Sec. 3	35–39	0.0	61.0	25.0	10.0	4.0
Sec. 4	51–55	0.0	20.0	46.0	14.0	20.0
Sec. 5	63–67.5	1.0	27.0	29.0	19.0	24.0
Core 6						
Sec. 1	0–4	7.0	82.0	7.0	2.0	2.0
Sec. 2	27–31	10.0	77.1	5.9	4.0	3.0
Sec. 3	40.5–44.5	9.0	75.0	14.0	2.0	0.0
Sec. 4	57.5–61.5	2.0	64.0	17.5	9.0	7.5
Sec. 5	74–78	4.5	28.5	27.0	20.0	20.0
Sec. 6	94.5–99	3.0	25.5	28.2	17.3	26.0
Tow 6	....	0.0	22.5	37.0	12.0	16.0
CANYON III						
Core 7						
Sec. 1	0–4	5.3	60.7	20.0	6.0	8.0
Sec. 2	27.5–31.5	0.1	35.0	36.6	12.1	16.2
Sec. 3	56–60	1.5	24.5	40.5	13.5	20.0
Sec. 4	78–82	0.0	17.0	43.0	22.0	18.0
Sec. 5	93.5–97.5	1.0	17.2	42.8	16.8	22.2
Sec. 6	112–116	3.0	30.0	31.5	11.5	24.0
Core 8						
Sec. 1	0–4	0.0	73.0	17.2	7.8	2.0
Sec. 2	28.5–32.5	0.0	68.0	21.0	3.5	7.5
Sec. 3	54–58	0.0	58.0	25.6	8.4	8.0
Sec. 4	79–83.5	0.0	54.5	27.5	6.0	12.0
Core 9						
Sec. 1	0–4	0.5	93.5	3.0	3.0	0.0
Sec. 2	18.5–22.5	0.5	90.5	6.0	3.0	0.0
Sec. 3	37–41	0.0	89.0	7.5	2.5	1.0
Sec. 4	50–53.5	0.4	86.0	9.6	2.0	2.0
Core 10						
Sec. 1	0–4	0.2	86.0	10.3	1.1	2.4
Sec. 2	22.5–26.5	0.2	84.7	11.6	1.2	2.3
Sec. 3	45–49	0.0	87.0	8.5	0.5	4.0
Core 11						
Sec. 1	0–5	1.2	87.8	7.3	1.2	2.5
Sec. 2	10.5–15	0.0	77.7	12.3	7.5	2.5
Tow 9	....	0.0	35.0	37.0	12.0	16.0
Tow 11	....	0.0	18.5	47.5	14.0	20.0

survey of the Chesapeake canyon was extended farther seaward than any of the others, and, consequently, that canyon appears to have been cut to greater depths.

GEORGES BANK AND THE GULF OF MAINE

The origin of the series of fishing banks, stretching from Georges to the Grand Banks, has long provoked discussions. Many theories have been proposed to account for them, including terminal moraines and debris from melting shore ice and icebergs. Spencer[20] and Upham[21] considered that they were submerged extensions of the Coastal Plain.

The latter theory can now be substantiated, if one accepts as valid the arguments advanced in the preceding sections. The Upper Cretaceous-Tertiary contact is found between 600 and 480 meters below sea level. If 75 fathoms, or 137 meters, is taken as the average depth of water over the flat top of the shelf between the canyons, the entire thickness of sediments over the Upper Cretaceous at this point can not exceed 560 meters. It is, of course, unlikely that the extreme top of the Upper Cretaceous was encountered at the exact start of the tow, and, furthermore, allowance must be made for an undetermined thickness of glacial deposits. Therefore, the total thickness of Tertiary and Recent can not be more than 450 to 500 meters, and may well be much less. There are no data at present that can throw light on the total thickness of the sedimentary wedge over the basement crystallines at the continental margin.

The evidence indicates that the continental shelf of this part of the coast has probably grown forward and upward after the manner of delta deposits. The fossiliferous material came, therefore, from what would correspond to the foreset beds, and the dip of these beds determined the initial angle of the continental slope. This angle was, doubtless, somewhat modified by erosion during the period of uplift, and, as shown by the youthful topography of the canyons, the period was brief. The persistence of these physiographic features indicates that present-day deposition is slow. This is further emphasized by the fact that this deposit was not thick enough to prevent the dredge from cutting through into glacial material on the upper slopes. At the present time the continental slope must therefore be growing forward very slowly.

The presence of the Gulf of Maine adds further difficulties to an already complicated problem. Johnson[22] considers that the floor of the Gulf of

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[20] J. W. Spencer: *Submarine valleys off the American Coast and in the North Atlantic*, Geol. Soc. Am., Bull., vol. 14 (1903) p. 207-226.

[21] Warren Upham: *The fishing banks between Cape Cod and Newfoundland*, Am. Jour. Sci., 3rd ser., vol. 47 (1894) p. 123-129.

[22] D. W. Johnson: *The New England-Acadian shore line*, chap. 8 (1925). New York.

Maine has all the characteristics of a maturely dissected inner lowland, bounded on the seaward side by typical Coastal Plain cuestas facing north. Georges Bank is the largest of these, but the lowland contains many subordinate ones. The analogy with conditions in New Jersey would be close were that State to be submerged. Shepard [23] subscribes in part to that opinion, but is inclined to attribute the present form of the basin to re-excavation of the old inner lowland by the ice sheet, assuming that it had been filled during the formation of the continental shelf.

It is, of course, necessary to assume that, at some time prior to the deposition of the Coastal Plain wedge, the basement crystallines were eroded to form what is now a broad re-entrant in the coast line. Subsequent elevation and a second period of erosion would strip the thin edge of sedimentary from the crystalline rock, and at the same time cut the bordering cuestas, making the Gulf a true basin. The contact is now submerged below the waters of the Gulf, and everywhere along its shores, except for small stretches of glacial deposits, the ancient crystalline rocks are once more exposed. According to Johnson,[24] present marine erosion of the shore line is negligible.

The time necessary for excavating a large basin like the Gulf must have been many times that required for cutting narrow gorges. Similarly, if the Gulf had been formed after the canyons, the time necessary to produce it would have been more than sufficient to have permitted the grading back of the upper parts of the canyon walls, and to have largely obliterated the angle between them and the level surface of the shelf. An uplift of about 1200 feet, which is required for the Gulf, would bring the upper part of the canyon walls 600 to 800 feet out of water. Profiles show that the same V-shape that characterizes the lower part is continued to the top. Furthermore, it is reasonable to assume that all the canyons were cut during the same uplift, so similar are they in size and shape. The whole shelf must, therefore, have been out of water to permit this. If the Gulf and the canyons formed simultaneously, there is no good reason why the same physiographic features should not have developed in the equally broad expanse of soft sedimentary rocks farther south, especially as cuestas and inner lowlands are developing today on the subaerial portion of the Coastal Plain.

If, as the evidence requires, one postulates a Gulf older than the canyons, he has then to explain why its floor, which must have stood at least 7000 feet above sea level, is not more deeply trenched. The inner part is floored by hard basement crystalline rocks and would erode slowly, but the outer part, especially in the region of the present cuesta face, being in all probability of weak sedimentary rock, might be expected to retain some trace of overdeepening had it occurred. A river draining the Gulf, with an outlet between Georges Bank and Browns, or between Browns and Cape Sable, would not have graded a channel across the shelf, if the arguments advanced for the case of the Hudson are valid, any more than the southern rivers have done. Deep trenching, therefore, could not take place in the floor of the Gulf, had no tilting occurred, until the outer gorge had been able to cut back into it by headward erosion. There is no evidence that any such channel ever entered the basin. In fact, the controlling depth of the southerly outlet, which is the deeper of the two, is somewhat shallower than parts of the Gulf itself. If this be a natural condition, and not due to later glacial fill, parts of the inner basin would have been a lake during the time of uplift. In all probability, there is a canyon, similar to the ones under discussion, opposite the outlet between Georges and Browns Bank. The abrupt changes in depth give every indication that one exists. However, present surveys are not adequate to show this feature with any degree of precision.

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[23] F. P. Shepard, J. M. Trefethen, and G. V. Cohee: *Origin of Georges Bank*, Geol. Soc. Am., Bull., vol. 45 (1934) p. 287.

[24] D. W. Johnson: *op. cit.*

SHIFTS IN LEVEL

The difficulties in the way of an acceptance of the theory of fluviatile origin cannot be minimized in the least. To obtain a shift in level such as the presence of the canyons implies, only two courses are open: (1) an orogenic movement involving a very large portion of the eastern seaboard; (2) a world-wide lowering and raising of sea level of enormous extent. This relative shift, amounting to more than 8,000 feet, must have occurred since the late Tertiary. The erosional unconformities that are found within the Coastal Plain, indicate that the continental shelf has oscillated somewhat, but that a shift of base level of the order of magnitude demanded here could have taken place, runs counter to generally accepted theories.

If one accepts the first alternative, the fact that all the canyons are cut to about the same depth implies that a segment of the earth's crust, reaching from Georges, and possibly the Grand Banks, to Cape Hatteras, underwent a uniform elevation. So long a section with no differential movement discernible in its entire length is unusual. Furthermore, that portion of the Atlantic Coastal Plain which is now above sea level shows little evidence of any orogenic movements. If one assumes a like condition for the submerged portion, any movement which elevated the continental margin must have been in the form of a block uplift, or a simple tilt, with the fulcrum at, or west of, the Piedmont boundary.

The other horn of the dilemma is equally difficult to avoid. A fall and a rise of sea level of the order of magnitude which the evidence demands, coupled with the shortness of the time within which it must have taken place, approaches the catastrophic.

Nevertheless, one must not forget that from the point of view of the physical oceanographer, submarine currents of the type demanded here, based on differential densities due to temperature and salinity, are equally unacceptable. Daly's density currents call for special conditions to make them operative. Whatever may be the verdict of the future, one must at present regard the question as still subject to modification, and be slow to reject completely the testimony offered by the configuration of these valleys, evidence which under other conditions would scarcely be questioned.

SUMMARY AND CONCLUSIONS

(1) Fragments of a coarse sandstone (Lower Monmouth or Upper Matawan), of a glauconitic greensand (Navarro), of an indurated, green silt, not older than Miocene, and of an impure glauconitic sandstone, late Tertiary in age, were broken from the walls of the newly charted canyons cutting the southern margin of Georges Bank.

(2) The contact between the Upper Cretaceous and the younger sediments occurs between 480 and 600 meters below present sea level, and the total thickness of the younger sediments cannot be more than 450 to 500 meters.

(3) The fossiliferous material probably came from truncated strata forming the actual walls, and not from sheets of fill in an older cut.

(4) Glacial and Recent materials mantle all the gentler slopes, but in several instances the older formations stand as cliffs with no covering of any sort.

(5) Glacial erratics were not found on the valley bottoms. If present, the accumulation of fine sediments, due to quiet water conditions, has buried them.

(6) A fine silt with a present-day Arctic foraminiferal fauna was encountered in several places in the valley bottom, under a thin cover of present-day sediment. It is probably made up of the finer particles derived from the melting of the Pleistocene ice sheets.

(7) Due to the special topographic conditions of the continental shelf, any streams flowing across it could only have attained graded channels when the falls caused by the break in slope had worked headward through its entire width. The outer gorge of the Hudson is regarded as an illustration of this point.

(8) Many of the canyons may be due to ground-water sapping, aided by small streams working back into a plateau from the face of a scarp, rather than to large streams flowing out of the hinterland and cascading

down the continental slope. Many side canyons formed by this means are excellently shown on the United States Geological Survey topographic sheet of the Bright Angel quadrangle, Arizona. Origin by rifting or block faulting is extremely unlikely, and an origin due to density currents caused by differences in temperature and salinity is regarded as impossible. This does not apply to the theory recently put forward by Daly, in which the differential densities were obtained by sediment in suspension. This current would become operative under the special conditions which may have obtained during the Pleistocene.

(9) The Gulf of Maine must have been in existence during the time of canyon-cutting, and the depth of the canyons indicates that its floor stood at least 7,000 feet above sea level. Deep trenching of its floor could not have occurred until the stream draining it had graded a channel across the shelf.

(10) At least the upper part of Georges Bank is an extension of the Coastal Plain covered with a mantle of glacial debris.

(11) At the present writing, the question of subaerial versus submarine origin of the canyons is regarded as still open. The evidence at hand does not warrant a complete rejection of either view.

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GEOLOGY AND PALEONTOLOGY OF THE GEORGES BANK CANYONS

Part II. UPPER CRETACEOUS FOSSILS FROM GEORGES BANK (INCLUDING SPECIES FROM BANQUEREAU, NOVA SCOTIA)

BY LLOYD WILLIAM STEPHENSON

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INTRODUCTION

The material from Georges Bank, described in this paper, was submitted to John B. Reeside, jr., Chief of the Section of Paleontology of the United States Geological Survey, by Henry C. Stetson, Assistant Curator of Paleontology, Museum of Comparative Zoology, and Research Associate in Submarine Geology, and was subsequently placed in the writer's hands for identification and description. The material was dredged by the ketch *Atlantis* on August 8, 1934, under the direction of Stetson, who, under the auspices of the Woods Hole Oceanographic Institution, is in charge of their studies of sediments, past and present, on the Continental Shelf off the eastern coast of the United States. Stetson was assisted by Marshall Schalk.

Most of the material submitted consists of coarse, gray, conglomeratic, calcareous, fossiliferous sandstone. The fossils are preserved mainly in the form of molds, but the shells of *Exogyra* and a few other shells found in the inner, uncorroded portions of the sandstone, remain intact; one small piece of ferruginous, fossiliferous sandstone is reddish, fine grained, and evidently came from a layer distinct from the gray sandstone. The gray and red sandstones were dredged from between depths of 480 and 596 meters (1574 to 1955 feet) at Latitude North 40°24′30″, Longitude West 69°07′30″. The method used in dredging precluded the determination of the exact depth of the fossil-bearing sandstone. The sea bottom at this locality forms a part of the west-facing slope of one of the several short deep submerged gorges which cut the edge of the Continental Shelf along the south side of Georges Bank. According to Stetson, the pieces of gray conglomeratic sandstone from which most of the fossils were obtained were broken by the dredge from a layer of rock "cropping out" in place on the sea bottom along the side of the gorge.

The securing of identifiable fossils as old as Upper Cretaceous, from deeply submerged rock in place on the sea bottom, is a feat unique in the annals of fossil collecting and evidences the ingenuity and resourcefulness of the collector.

Although many of the fossils are incompletely and imperfectly preserved, fully 20 genera and subgenera of marine organisms are identifiable, and more than 30 species are represented. The recognition of this rather large number of organisms is made possible by the careful and skillful manner in which the material was prepared by F. Stearns MacNeil, of the United States Geological Survey, who also assisted in the generic determination of some of the pelecypods.

The fossils obtained are not the first Upper Cretaceous fossils dredged from the Continental Shelf off the Atlantic Coast of North America. In 1925, William H. Dall[1] published a list of Upper Cretaceous fossils from the eastern part of Banquereau, Nova Scotia. These fossils are the property of Peabody Museum, Yale University, and were kindly lent to the writer, by the Peabody authorities, with permission to prepare the material as seemed desirable, and to describe the fossils.

The fossils from both Georges Bank and Banquereau were photographed in the photographic laboratory of the United States Geological Survey by N. W. Shupe, and were retouched by Frances Wieser, of the same bureau. A few of the illustrations are brush drawings made by Miss Wieser.

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[1] W. H. Dall: *Tertiary fossils dredged off the northeastern coast of North America*, Am. Jour. Sci., 5th ser., vol 10 (1925) p. 215.

FOSSILS FROM GEORGES BANK

ENUMERATION AND SIGNIFICANCE

The fossil organisms recognized in the sandstone from Georges Bank are as follows:

- Vermes:
  - *Serpula* (probably two species)
- Echinodermata:
  - *Hardouinia*(?) *stetsoni* Stephenson n.sp.
- Molluscoidea:
  - *Plethopora americana* Bassler n.sp.
- Mollusca (Pelecypoda):
  - *Glycymeris subcrenata* Wade
  - *Postligata schalki* Stephenson n.sp.
  - *Postligata*(?) *greenensis* (Stephenson)
  - *Exogyra ponderosa erraticostata* Stephenson
  - *Exogyra* sp.
  - *Gryphaeostrea vomer* (Morton)
  - *Trigonia* sp.
  - *Anomia* cf. *argentaria* Morton
  - *Liopistha* sp.
  - *Crassatellites roodensis* Stephenson
  - *Crassatellites*? sp.
  - *Cardium (Trachycardium) longstreeti* Weller?
  - *Cardium (Trachycardium) vaughani* Stephenson
  - *Cardium (Trachycardium)* sp.
  - *Cardium (Crinocardium) atlanticanum* Stephenson n.sp.
  - *Cyclina parva* Gardner?
  - *Tellina* sp. *a*.
  - *Tellina* sp. *b*.
  - *Tellina* sp. *c*.
  - *Tellina* (?) sp. *d*.
  - *Cymbophora* sp.
  - *Donax*(?) *atlantis* Stephenson n.sp.
  - *Corbula* sp. *a*.
  - *Corbula* sp. *b*.
- Mollusca (Gastropoda):
  - *Polinices*(?) sp.
  - Turritella-like gastropods (5 or 6 species, poorly preserved)
  - *Cerithium georgesensis* Stephenson n.sp.

The list indicates the presence of one genus of marine worm, probably represented by 2 species; one species of echinoid; one species of bryozoa; 14 genera and subgenera of pelecypods, representing 23 or more species; and 3 or more genera of gastropods, probably representing 7 or 8 species.

The few poorly preserved marine worm tubes (Phylum Vermes) from Georges Bank are referred to the genus *Serpula* Linnaeus; they are inadequate for determining the geologic age of the containing sandstone.

The echinoid, *Hardouinia* (?) *stetsoni*, the one representative of the phylum Echinodermata, indicates an Upper Cretaceous age; its nearest ally among previously described species is *Hardouinia* (?) *emmonsi* (Stephenson),[2] from the upper part of the Peedee formation (*Exogyra costata* zone) of North Carolina.

The bryozoan, *Plethopora americana* Bassler, described by R. S. Bassler on page 411, belongs to an Upper Cretaceous genus recorded from the Senonian of Europe.

Among the bivalves (Pelecypoda), *Postligata* (?) *greenensis* (Stephenson), *Crassatellites roodensis* Stephenson, *Cardium* (*Trachycardium*)

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[2] L. W. Stephenson: *Additions to the Upper Cretaceous invertebrate faunas of the Carolinas*, U. S. Nat. Mus., Pr., vol. 72, art. 10 (1927) p. 7, pl. 3, figs. 3-8; pl. 4.

longstreeti Weller?, and *C.* (*T.*) *vaughani* Stephenson appear to be identical with species restricted to the Snow Hill marl member of the Black Creek formation (upper part of *Exogyra ponderosa* zone) of North Carolina,[3] and to beds of equivalent age in the Atlantic Coastal Plain. *Glycymeris subcrenata* Wade occurs in the Coon Creek tongue of the Ripley formation (*Exogyra cancellata* zone = lower part of *Exogyra costata* zone) in Tennessee. *Cyclina parva* Gardner is present in the Monmouth formation (*Exogyra costata* zone) of Maryland, and in the Coon Creek tongue of the Ripley formation in Tennessee. *Exogyra ponderosa erraticostata* Stephenson is common in the upper part of the *Exogyra ponderosa* zone in the Atlantic and Gulf Coastal Plain, and in North Carolina ranges upward into the lower part of the Peedee formation (*Exogyra cancellata* zone). *Gryphaeostrea vomer* (Morton) and *Anomia argentaria* Morton are long-ranging forms in the zones of *Exogyra ponderosa* and *E. costata*, and are not of value in close correlation; the former ranges from the Cretaceous well up into the Eocene. The new species are, of course, of no assistance in exact correlation.

The fossils enumerated definitely prove the Upper Cretaceous age of the containing sandstone, and the weight of the evidence appears to indicate a stratigraphic position either in the upper part of the *Exogyra ponderosa* zone or in the lower part of the *Exogyra costata* zone (=*Exogyra cancellata* zone). In terms of the New Jersey and Maryland Upper Cretaceous section this would correspond in age to the upper part of the Matawan group or to the lower part of the Monmouth group. In terms of the standard European time section it would be upper Campanian, or possibly lower Maestrichtian.

The place nearest to Georges Bank at which Upper Cretaceous fossils have been found on land is on Martha's Vineyard. These fossils are listed and discussed by the writer in the recent work of Woodworth and Wigglesworth.[4] Although the fossil-bearing beds at Martha's Vineyard have been greatly disturbed by the shove of glacial ice, they have not been moved far from their original position. They are interpreted as indicating an age corresponding to some undetermined part of the Matawan group of New Jersey. Only one species, *Anomia argentaria* Morton, is listed as common to the Martha's Vineyard and the Georges Bank localities; at the latter locality the species is questionably identified.

Previous records of Cretaceous and Tertiary fossils[5] from the banks off the New England and Canadian coasts have been based on loose material, most of which had been brought to the surface entangled in fishermen's trawls. The fossils thus obtained have been accepted as evidence of a completely submerged northeastward extension of the Coastal Plain, the last appearance of which above sea level is on the islands of the Cape Cod region. The fossils herein described, which were deliberately dredged from rock believed to be in place in the side of a submerged gorge on Georges Bank, constitute further confirmatory evidence of the correctness of this interpretation. One may, therefore, picture the Coastal Plain as passing beneath sea level off the southern coast of New England and continuing to the northeast as a long series of banks (Georges, Browns, La Have, Emerald, Sable Island, Banquereau, and Grand Banks of Newfoundland), whose masses are mainly composed of a series of Cretaceous and Tertiary strata.

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[3] L. W. Stephenson: *The Cretaceous formations of North Carolina; Part I, Invertebrate fossils of the Upper Cretaceous formations.* N. C. Geol. and Econ. Surv., vol. 5 (1923) p. 107, 273, 287, 289.

[4] J. B. Woodworth and Edward Wigglesworth: *The geology and geography of the Cape Cod region,* Mus. Comp. Zoöl., Harvard College, Mem., vol. 52 (1934) p. 150-155.

[5] W. H. Dall: *op. cit.*, p. 213-218 [includes references to other papers].

SYSTEMATIC DESCRIPTIONS

Phylum VERMES

UNIDENTIFIED SPECIMENS OF *Serpula* LINNAEUS

(Plate 1, figure 1)

The internal and external molds of small sinuous *Serpula* tubes, which were originally attached to the inner surface of *Glycymeris subcrenata* Wade, are impressed in the internal molds of two shells. The larger of the two is 0.2 millimeter in diameter at the small end, and 0.5 millimeter in diameter at the large end. Crenulations along the margins of the external mold indicate that the outer surface of the tube was covered with fine, sharp growth ridges. (Figured specimen is Museum of Comparative Zoology, Specimen No. 1011; unfigured specimen, M.C.Z. 1012.)

The external mold of a fragment of a *Serpula* tube (M.C.Z. 1013), with part of the calcareous tube preserved and about half of the internal mold remaining in place, indicates a rapidly tapering tube with a rather thin tube wall. The fragment is 22 millimeters long, and the diameters at the small and large ends are respectively 2.5 and 5 millimeters.

A fragment of the internal mold of another tube (M.C.Z. 1014) is 4 millimeters long and about 2 millimeters in diameter.

Phylum ECHINODERMATA

Hardouinia(?) *stetsoni* Stephenson n.sp.

(Plate 1, figures 2-4)

Description.—Test of medium size, broadly ovate in basal outline, moderately high and dome-shaped. Base broadly concave with peristome slightly in advance of the center; two broadly expanding concave areas radiate from the peristome to the ambitus, one on either side of a low posterior swelling, the plastron, which ends at the rear in a slight protuberance or subangulation below the periproct; a slight protuberance on the ambitus also marks the outer corner of each of the two concave areas at equal distances from the outer end of the plastron; the protuberances and concave areas produce slight truncations on the ambitus on either side of the posterior center; the ambital outline in front forms an approximate semi-circle, and the lateral margins are slightly subtruncated. The test is slightly humped above the periproct. Dimensions: Length 35.6 millimeters; width, 33.5 millimeters; height, 16.6 millimeters.

The petals are lanceolate, with a width of 3 to 3.5 millimeters a little above their mid-length, and they narrow down to 1.5 millimeters, or less, at their distal ends; they extend about 0.7 the distance from the apex to the ambitus. The pores in the petals form two double rows separated by a slightly raised area; the pores are small and are connected by very narrow furrows, which are narrower than the intervening ridges; the inner pore of each pair is nearly circular, and the outer one is noticeably elongated; the pore pairs are closely spaced, and the connecting furrows trend obliquely downward away from the center of the petal. The ambulacral areas from the lower ends of the petals to the peristome are obscured by corrosion and by sand-grain pitting, which have slightly damaged the whole surface of the test. The five floscelles surrounding the peristome may be obscurely seen and appear to be typical of the genus. The ambulacral and interambulacral plates are too obscure for description.

The apical system is situated slightly in advance of the center; it is obscure, owing in part to corrosion and in part to a rather wide crack which cuts laterally across it.

The peristome is not well preserved but is surrounded by five prominent oral lobes such as are typical of the genus.

The periproct is circular, deep-set, of medium size and situated well above the ambitus; a broad shallow sulcus connects it with the ambitus.

The test, exclusive of the pore bands on the petals is densely crowded with small tubercles and granules which, as preserved, are obscure over considerable parts of the surface; each of the tiny bosses appears to lie within a narrow scrobicular circle.

Remarks.—This species is referred to *Hardouinia* Haime, on the authority of Lambert and Thiéry,[6] who, however, treated this group as a subgenus of *Procassidulus* Lambert and Thiéry; the latter assignment hardly seems justified if the published figures of *Echinites lapiscancri* Leske,[7] the genotype, are accurate. The genotype of *Hardouinia* is *Pygorhynchus mortoni* Michelin, of which *Cassidulus subquadratus* Conrad is said by Lambert and Thiéry to be a synonym. The latter conclusion may be correct, but should be accepted with some reservation until the types of the two species are critically compared.

Hardouinia(?) *stetsoni* is nearly identical in form with *H.*(?) *emmonsi* (Stephenson)[8] from the Peedee formation of North Carolina, but differs in its noticeably coarser pattern of tubercles over the entire surface; on a selected part of the surface, 9 tubercles were counted in a distance of 3 millimeters, whereas on the corresponding part of *H.*(?) *emmonsi* there were 12 tubercles; 7 tubercles were counted across the widest part of one of the petals, as compared with 15 across the corresponding petal of *H.*(?) *emmonsi.*

Type.—Holotype, Museum of Comparative Zoölogy (M.C.Z. 3516), Harvard College, Cambridge, Massachusetts.

Occurrence.—Atlantic Ocean, Georges Bank, Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters.

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[6] J. Lambert and P. Thiéry: *Essai de nomenclature raisonnée des échinides,* Fasc. 5 (1921) p. 362.

[7] A. d'Orbigny: *Paléontologie française, Crétacé,* T. 6 (1853-1859) p. 327, pl. 925.

[8] L. W. Stephenson: *Additions to the Upper Cretaceous invertebrate faunas of the Carolinas,* U. S. Nat. Mus., Pr., vol. 72, art. 10 (1927) p. 7, pl. 3, figs. 3-8; pl. 4.

Phylum MOLLUSCA

Class Pelecypoda

Glycymeris subcrenata Wade

(Plate 1, figures 5-7)

1926. *Glycymeris subcrenata* Wade, U. S. Geol. Surv., Prof. Pap. 137, p. 48, pl. 11, figs. 7 and 8.

Description.—Shell of medium size moderately depressed, subcircular in outline but generally slightly longer than high. Beaks small, protruding slightly above the hinge line, gently incurved, faintly prosogyrate, situated centrally.

Hinge plate broadly arched, truncated above by the straight lower margin of the cardinal area; on an adult, about a dozen of the centrally located teeth are small, short, and transverse to the hinge line; away from these central teeth in both directions on the broader parts of the hinge the teeth become first longer and progressively more oblique, followed outwardly by successively shorter and more oblique teeth. Area amphidetic, broad centrally, straight on lower margin, ornamented in an adult with 7 or 8 closely crowded chevron-shaped ligamental grooves, the posterior limb of each of which is the longer.

Adductor scars high in the shell, subequal, somewhat elongated apically, each bounded on the inner side by a shallow radial sulcus. Pallial line simple. Inner margin weakly and rather finely crenulated.

Surface nearly smooth, with fine incremental lines which tend to become coarser toward the ventral margin, and with fine, weak radiating lines on the least corroded portions; corroded specimens reveal coarser radiating structural lines within the shell substance, which correspond to the marginal crenulations.

Approximate dimensions of the specimen shown in Plate 1, figure 6: Length, 34 millimeters; height, 33 millimeters; convexity, 6.5 millimeters.

Remarks.—In form and in the smoothness of the shell, this species is essentially like *Glycymeris subcrenata* Wade,[9] from Coon Creek, Tennessee. The inner margin of the holotype, the only specimen seen by Wade, is nearly smooth, but that shell is a half grown individual on which the crenulations have not become clearly differentiated; the stage at which the crenulations develop probably varies somewhat with different individuals.

The two internal molds described by Weller,[10] under the name *Axinea microdentus*, appear to be closely allied to this species, but their surface characters are not preserved, and they can scarcely be regarded as specifically identifiable.

G. subcrenata is the most common of the fossils in the Georges Bank collection.

Type.—Holotype, U. S. National Museum Cat. No. 32733; from the Coon Creek tongue of the Ripley formation, at Coon Creek on the Dave Weeks farm, McNairy County, Tennessee.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from depths between 480 and 596 meters. Figured specimens, M.C.Z. 15076, 15077, 15078; unfigured specimens, M.C.Z. 15079.

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[9] Bruce Wade: *The fauna of the Ripley formation on Coon Creek, Tenn.*, U. S. Geol. Surv., Prof. Pap. 137 (1926) p. 48, pl. 11, figs. 7 and 8.

[10] Stuart Weller: *A report on the Cretaceous paleontology of New Jersey, based upon the stratigraphic studies of George N. Knapp*, N. J. Geol. Surv., *Paleontology*, vol. 4 (1907) p. 416, pl. 35, figs. 10 and 11.

Postligata schalki Stephenson, n.sp.

(Plate 1, figure 8)

Description.—Shell small, depressed, broadly subovate in outline, elongated in the postero-ventral direction. Beak small, nonprominent, slightly prosogyrate, situated well forward. Lunule and escutcheon wanting. Antero-dorsal margin slightly subtruncated; anterior margin rather sharply rounded, passing below into the broadly rounded ventral margin; posterior margin rather sharply rounded below, passing above into a long, broadly arched postero-dorsal margin. Surface smooth with the exception of regular, closely spaced incremental threads.

Hinge taxodont, the teeth numerous and arranged in two series; the anterior series is inclined downward and forward from the beak and curves gently, with the concavity on the upper side; the posterior series inclines downward and backward from the beak and is broadly arched upward. The area is narrow and obscure as preserved. Other internal features are not uncovered.

Dimensions: Length, 7.4 millimeters; height, 7.5 millimeters; convexity, 2 millimeters.

Remarks.—The species is based on one well-preserved left valve, and an incomplete mold of a right valve. It differs from *Postligata wordeni* Gardner, and from *P. crenata* Wade, in the strong obliquity of the shell.

Types.—Holotype, Museum of Comparative Zoölogy, Harvard College, Cambridge, Massachusetts (M.C.Z. 15080); paratype (M.C.Z. 15081). Named in honor of Marshall Schalk, who assisted Stetson in his investigations on Georges Bank.

Occurrence.—Atlantic Ocean, Georges Bank, Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters.

Postligata greenensis (Stephenson)

(Plate 1, figure 9)

1923. *Glycymeris*(?) *greenensis* STEPHENSON, N. Car. Geol. and Econ. Surv., vol. 5, p. 107, pl. 18, figs. 9 and 10.

Description.—Shell small, strongly depressed, very broadly subovate in outline. Beak small, nonprominent, very faintly prosogyrate, situated slightly in advance of the mid-length. Antero-dorsal margin inclined, slightly arched; anterior margin regularly rounded; ventral margin broadly rounded; posterior margin regularly rounded below, passing upward into the gently arched postero-dorsal margin. Surface smooth with only fine incremental lines.

Hinge and dorsal margin waterworn, but the dentition is taxodont in the two series typical of the genus. Other internal features not uncovered.

Dimensions: Length, 10.7 millimeters; height, 10.7 millimeters; convexity, 1.8 millimeters.

Remarks.—Compared with *Postligata schalki* this shell is more broadly subovate, much less oblique, and less inflated. Since the original description of the species, which was based on one shell, the species has been found in considerable numbers in the Snow Hill marl member of the Black Creek formation, at Mars Bluff, Peedee River, South Carolina.[11]

Type.—Holotype, Academy of Natural Sciences of Philadelphia; from the Snow Hill marl member of the Black Creek formation, at Snow Hill, Greene County, North Carolina.

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[11] L. W. Stephenson: *Additions to the Upper Cretaceous invertebrate faunas of the Carolinas,* U. S. Nat. Mus., Pr. (No. 2706), vol. 72, art. 10 (1927) p. 4.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimen, M.C.Z. 15082.

Exogyra ponderosa erraticostata Stephenson

(Plate 1, figure 10)

1914. *Exogyra ponderosa* var. *erraticostata* STEPHENSON, U. S. Geol. Surv., Prof. Pap. 81, p. 49, pl. 15, fig. 4; pl. 16, figs. 1 and 2.

1923. *Exogyra ponderosa* var. *erraticostata* STEPHENSON, N. Car. Geol. and Econ. Surv., vol. 5, p. 171, pl. 47, fig. 1.

Description.—Shell of medium size, strongly convex, elongated in the direction of the height, rather thin for the genus; the beak has the characteristic twist of the genus, but is partly suppressed by the large scar of attachment.

Hinge incompletely preserved, but apparently normal for the genus.

Adductor scar large, subovate, situated high in the shell.

Surface ornamented on the anterior and ventral slopes by strong, roughly irregular costae. The scar of attachment is large, occupying the upper half of the posterior slope; it is exceedingly irregular, due to the rough jagged surface of the object to which it was attached; the lower half of this slope is noncostate, but is roughened by irregular growth undulations.

Dimensions: Length, 60+ millimeters; height, 78 millimeters; convexity, 29 millimeters.

Remarks.—Compared with the type of the variety, this specimen is typically ornamented, but the costae are somewhat more strongly developed. The elongated outline suggests that the shell grew in a crowded position.

This varietal form is of common occurrence in the zone of *Exogyra ponderosa* in the Atlantic and Gulf Coastal Plain, but in North Carolina it ranges upward into the basal part of the Peedee formation, where it is associated with *Exogyra cancellata* Stephenson and *Exogyra costata* Say.

Type.—The holotype is from the lower part of the Selma chalk (*Exogyra ponderosa* zone), a mile west of Cotton Gin Port, Monroe County, Mississippi (U. S. National Museum Cat. No. 31225).

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimen, M.C.Z. 15083.

Exogyra sp.

(Plate 1, figure 11)

Description.—A small shell of *Exogyra* Say is strongly twisted and is ornamented on the steep anterior and ventral slopes with 11 weak, regular costae. Most of the posterior slope is affected by the scar of attachment, which is exceedingly rough and jagged. The surface of the shell toward the ventral margin appears to be abnormally thickened. Figured specimen, M.C.Z. 15084.

Dimensions: Length, 36.8 millimeters; height, 32.5 millimeters; convexity, about 13 millimeters.

Remarks.—This specimen may perhaps be regarded as a small, nontypical representative of *E. costata* Say, such as are occasionally met with in the zone of *Exogyra ponderosa*.

Gryphaeostrea vomer (Morton)

(Plate 1, figure 12)

1828. *Gryphaea vomer* MORTON, Philadelphia Acad. Nat. Sci., Jour., vol. 6, p. 83.

1834. *Gryphaea vomer* MORTON, Synop. Org. Rem. Cret. Group, p. 54, pl. 9, fig. 5.

Description.—This species is represented in the collection by one incomplete internal mold of a left valve in a coarse ferruginous sandstone. The same piece of rock bears the imprint of a large ribbed *Cardium (Trachycardium)* sp. The mold exhibits the characteristic backward twist of the beak of the species. The dimensions of the incomplete mold as preserved are: Length, 14 millimeters; height, 19 millimeters.

Remarks.—This is one of the most common species in the Upper Cretaceous deposits of the Atlantic and Gulf Coastal Plain, where it is found both in the zone of *Exogyra ponderosa* and in the zone of *E. costata.* It is one of the few species known to range from the Cretaceous into the overlying Eocene in New Jersey, Maryland, and the Gulf region.

Type.—Academy of Natural Sciences of Philadelphia. From the Vincentown sand (= "arenaceous strata") of Eocene age, near New Egypt, New Jersey.

Occurrence on Georges Bank.—Latitude 40°24′30″, Longitude 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimen, M.C.Z. 15085.

Trigonia sp.

(Plate 2, figure 15)

Description.—The collection contains one incomplete young individual showing a series of transverse, slightly curved, finely crenulated ribs on the dorsal surface, a series of strong ribs on the side separated by wider interspaces, and curving downward and strongly forward, and a nearly smooth band, about a millimeter wide, separating the two series of ribs. The internal mold reveals the characteristic hinge of *Trigonia* Bruguière. The specimen is related to *Trigonia eufaulensis* Gabb, from the Ripley formation at Eufaula, Alabama, but is too imperfect for precise identification. The length of the mold as preserved is 8+ millimeters. Figured specimen, M.C.Z. 15086.

Anomia cf. *argentaria* Morton

(Plate 1, figure 13)

Description.—One small, strongly convex left valve of *Anomia* Linnaeus may be a juvenile example of *A. argentaria* Morton. It is subcircular in outline and nearly smooth, but exceedingly faint, fine radial lines may be detected. The beak is situated somewhat back from the margin.

Dimensions: Length, 8.7 millimeters; height, 8.9 millimeters; convexity, 3 millimeters.

Type.—Academy of Natural Sciences of Philadelphia. From the Upper Cretaceous (Matawan formation?) near St. Georges, Delaware.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimen, M.C.Z. 15087.

Liopistha sp.

(Plate 2, figure 8)

Description.—The external mold of a small fragment of shell exhibits strong, closely spaced ribs, each of which bears on its crest a row of small round tubercles, spaced about half a millimeter apart. As tuberculated ribs of this sort characterize *Liopistha* Meek, it is concluded that this fragment belongs to that genus. Figured specimen, M.C.Z. 15088.

Crassatellites roodensis Stephenson

(Plate 1, figures 14-17)

1923. *Crassatellites roodensis* STEPHENSON, N. Car. Geol. and Econ. Surv., vol. 5, p. 273, pl. 68, figs. 1-4.

Description.—In point of numbers of individuals, this species is second only to *Glycymeris subcrenata* Wade, in the Georges Bank material. It is represented mainly by internal molds with, however, a few more or less imperfect external molds.

Most of the specimens agree well in size, outline, and form with the holotype. The shell is elongated, subtrigonal, depressed convex. The beak is small and is situated in advance of the mid-length. The umbonal ridge is of moderate strength. The posterior of the shell is narrow and is sharply rounded at the extremity.

Dimensions of the adult shell, the internal mold of which is shown in Plate 1, figure 15: Length, 41 millimeters; height, 29 millimeters.

Remarks.—The individuals vary somewhat in the proportion of length to height, in the position of the beak with respect to the length, and in the strength of the incrementals. The exterior mold of one young individual, about 17 millimeters long, exhibits unusually strong concentric ornamentation, and the molds of the still smaller shells, respectively 4.3 and 5 millimeters long, which may be the young of two species, are also strongly marked concentrically.

Type.—Holotype, U. S. National Museum Cat. No. 31747. The holotype is from Woolridge Landing (Roods Upper Bend), Chattahoochee River, Georgia.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimens, M.C.Z. 15089, 15090, 15091; unfigured specimens, M.C.Z. 15092.

Crassatellites(?) sp.

(Plate 2, figure 16)

Description.—Two internal pelecypod molds are too imperfect for generic identification, but are somewhat suggestive of *Crassatellites*. The molds indicate a subequilateral, depressed shell of broadly subovate outline, with strongly impressed, subequal adductor scars. The best preserved mold is 25 millimeters long and 17 millimeters high; the other mold is a few millimeters longer and higher. Figured specimen, M.C.Z. 15093; unfigured specimen, M.C.Z. 15094.

Cardium (Trachycardium) longstreeti Weller?

(Plate 2, figure 1)

1907. *Cardium longstreeti* WELLER, N. J. Geol. Surv., *Paleontology*, vol. 4, p. 579, pl. 63, figs. 21 and 22.

1923. *Cardium (Trachycardium) longstreeti* Weller? STEPHENSON, N. Car. Geol. and Econ. Surv., vol. 5, p. 289, pl. 71, figs. 4-8.

Description.—The collection contains several internal molds which agree well in outline and form with *Cardium longstreeti* Weller, from the Wenonah sand, New Jersey, and the Snow Hill marl member of the Black Creek formation, North Carolina.

The shell is of medium size, subcircular in outline, moderately convex. The beaks are moderately prominent, and the umbonal ridge is fairly well differentiated but is rounded on the crest. The inner margin of the shell is crenulated and indicates the presence of 34 or 35 radial ribs. The approximate dimensions of the figured internal mold are: Length, 28 millimeters; height, 28 millimeters; convexity, 9 millimeters.

Remarks.—This species belongs to a group of closely related Upper Cretaceous Cardiums which are generally found poorly preserved and are, therefore, difficult to identify with certainty. Other members of the group are *Cardium donohuense* Stephenson and *Cardium marsense* Stephenson.

Type.—Collection of the New Jersey Geological Survey, State Museum, Trenton, New Jersey.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimen, M.C.Z. 15095; unfigured specimens, M.C.Z. 15096.

Cardium (Trachycardium) vaughani Stephenson?

(Plate 2, figures 2, 3)

1923. *Cardium (Trachycardium) vaughani* Stephenson, N. Car. Geol. and Econ. Surv., vol. 5, p. 287, pl. 70, figs. 1-5.

Description.—Nine internal molds and several imperfect external molds in the collection appear to represent this species.

The shells are small to medium in size, somewhat elongated in the direction of the height, and moderately convex. The posterior margin is long and subtruncated. The beak is narrow and not very prominent, and the rounded umbonal ridge is somewhat elongated in the postero-ventral direction. The ribs number about 40. The figured internal mold measures: Length, 21.5 millimeters; height, 23 millimeters; convexity, about 8 millimeters.

Type.—U. S. National Museum Cat. No. 31936; from the Snow Hill marl member of the Black Creek formation, Snow Hill, North Carolina.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimens, M.C.Z. 15097, 15098; unfigured specimens, M.C.Z. 15099.

Cardium (Trachycardium) sp.

(Plate 2, figures 4, 5)

Description.—Several external molds of *Cardium (Trachycardium)* Mörch, including two large ones, are ornamented each with about 34 radial ribs which are more or less corroded, and not well enough preserved for specific identification. The internal mold corresponding to the best-preserved large external mold, a left valve, is also present in the collection. This form is broadly subovate in outline, a little higher than long, rather strongly and broadly inflated, and noticeably oblique in the postero-ventral direction; the greatest inflation is above the mid-height. The beak is of moderate breadth and strongly incurved, and the umbonal ridge is broadly rounded. These specimens do not appear to be assignable to any described species. Figured specimens, M.C.Z. 15100, 15101; unfigured specimens, M.C.Z. 15102.

The approximate dimensions of the left valve, shown in Plate 2, figure 4, are: Length, 35 millimeters; height, 37 millimeters; convexity, 12 millimeters.

Cardium (Criocardium) atlanticanum Stephenson, n.sp.

(Plate 2, figures 6, 7)

Description.—The description here given is based on one individual, preserved as an external and internal mold. The external view, shown in Plate 2, figure 6, is a reproduction of a photograph of a gutta-percha squeeze made from the external mold.

Shell of medium size, broadly subovate in outline, strongly and broadly convex, very slightly oblique. Beak moderately broad, not prominent, strongly incurved, nearly direct, situated at about the mid-length. Greatest inflation well above the mid-height; posterior slope steep, anterior slope a little less steep.

Ligamental groove short, very narrow, deep, bordered above by a narrow, prominent ridge, which, in turn, is paralleled above by a narrow sulcus flaring slightly distally; the ligamental groove is bordered below by a short, stout nymph which is slightly indented on its inner slope. Hinge incompletely preserved, only the posterior part showing; a short, stout, but nonprominent lateral tooth lies back of the end of the ligamental groove; there is a suggestion of a broken cardinal tooth below the beak, and below the tooth may be seen the margin of a deep cardinal socket.

Anterior and ventral margins broadly rounded; posterior margin subtruncated.

Adductor scars of medium size, subequal, broadly subovate, situated high in the shell. Pallial line simple and lying well back from the margin. Inner margin strongly crenulated by the projecting rib ends.

The outer surface is ornamented with 50 or more low to obscure, very narrow, radial ribs, separated by narrow interspaces bearing rows of spines of unequal prominence; the number of ribs can best be determined by counting the crenulations on the inner margin. Of the rows of spines, about 20 are strikingly more prominent than the others; all 20 rows increase in prominence distally. The spines of both the large and the small series are coarsest on the anterior slope, less coarse on the posterior slope, and least coarse in the intervening area. The spines in the large rows are thick and elongated and apically fuse together, forming pseudo-ribs; their thickened bases tend to obscure the weak immediately paralleling ribs. Over most of the shell, two rows of small spines intervene between two large rows, but a few single small rows occur between the large ones both on the anterior and on the posterior slopes. The small spines are low, weak, elongated, and tend to run together; they are strongest toward the outer margins, and fuse together into weak pseudo-ribs toward the beak.

Dimensions: Length, 19.3 millimeters; height, 22 millimeters; convexity, about 9 millimeters.

Remarks.—This species differs strikingly from other described species of *Cardium (Criocardium)* in the great radial elongation of the spines, in the weak development of the true ribs, and in the fusing of the elongated spines to form pseudo-ribs.

Type.—Holotype, Museum of Comparative Zoölogy, Cambridge, Massachusetts (M.C.Z. 15103); paratype (M.C.Z. 15104).

Occurrence.—Atlantic Ocean, Georges Bank, Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from depths of 480 to 596 meters.

Cyclina parva Gardner?

(Plate 2, figures 9, 10)

1916. *Cyclina parva* GARDNER, Md. Geol. Surv., *Upper Cretaceous* (2 vols.), p. 678, pl. 41, figs. 5 and 6.

1926. *Cyclina parva* Gardner. WADE, U. S. Geol. Surv., Prof. Pap. 137, p. 87, pl. 27, figs. 2 and 3.

Description.—This description is based on one internal mold of a right valve. Shell small, subcircular, moderately inflated. Beak prosogyrate, incurved, situated at about the mid-length. Greatest inflation below the beak, a little above the mid-height.

Antero-dorsal slope steep; other slopes rounding down regularly from the point of greatest inflation. The impression of the interior is not completely preserved, but the pallial line is well back from the margin. The right hinge was fairly well preserved when the mold was first broken from the rock, but was badly damaged in making a gutta-percha squeeze. However, a fairly good impression was obtained, and is shown in Plate 2, figure 10. Two long, oblique anterior cardinal teeth are clearly shown; these correspond to the two anterior cardinals on Gardner's Maryland species, but they appear to be proportionately a little longer; however, the type of the Maryland species is smaller, being only about 4 millimeters long; the posterior cardinal is obscure. The ligamental groove is of moderate length and is sharply impressed; it is bordered by a narrow but pronounced nymph. Surface not preserved, but may be safely assumed to be smooth.

Dimensions: Length, 6 millimeters; height, 6.3 millimeters; convexity, about 1.8 millimeters.

Type.—Holotype, on deposit in the United States National Museum.

Occurrence on Georges Bank.—Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters. Figured specimen (M.C.Z. 15106).

UNIDENTIFIED SPECIMENS OF *Tellina*

(Plate 2, figures 11-14)

Several small and large external and internal molds of shells belonging to *Tellina* Linnaeus are inadequately preserved for specific identification.

One of the large shells (M.C.Z. 15107) is an incomplete left valve, 33.5 millimeters high, and is estimated to be about 55 millimeters long (Pl. 2, figs. 11, 12). It is depressed, with broad gentle slopes toward the anterior and ventral margins, becoming moderately steep on the postero-dorsal slope. The beak is low and nonprominent and is situated slightly in advance of the mid-length. The surface is marked with very fine growth lines, and centrally there is a group of 10 or 12 faint, wavy ridges trending backward and slightly downward, apparently independent of the growth lines. The anterior adductor scar is ovate and rather deeply impressed. The hinge presents one strong cardinal tooth directed downward and a little forward, and, although this tooth is badly water worn, it is probably weakly bifid. There is a faint indication of an external ligamental groove.

An internal mold of a large right valve of *Tellina* (M.C.Z. 15108) is higher and more inflated than the one just described, and probably belongs to a different species (Pl. 2, fig. 13). This shell is 55 millimeters long and 42 millimeters high. The hinge presents one thick cardinal tooth directed downward and backward, with a deep trigonal socket directly below the beak; a short, broad anterior lateral socket is bordered on either side by thick round-crested claspers. A broad, deep pallial sinus, very faintly preserved, extends a little beyond the mid-length of the shell.

The external and internal molds of one small incomplete right valve, apparently of *Tellina* (M.C.Z. 15109), are about 20 millimeters long (estimated) and 12.5 millimeters high (Pl. 2, fig. 14). The shell is moderately inflated for the genus, and the dorsal slopes are steep. The beak is nonprominent and appears to be about centrally situated. There is a fairly well-defined, narrow, slightly concave escutcheon; this is bordered on the postero-dorsal slope by a broad, very shallow, radiating sulcus; there is also an exceedingly faint radiating depression just in front of the scarcely defined umbonal ridge. The surface is marked only by fine growth lines, two or three of which are a little stronger than the others. The hinge is obscurely preserved but exhibits a well-defined triangular socket below the beak, between two ill-defined cardinal teeth;

the anterior cardinal appears to be separated from a short, narrow anterior lateral by a pronounced gap; the posterior cardinal appears to be bifid, with an oblique socket back of it.

A very small internal mold including both valves (M.C.Z. 15110) is questionably referred to *Tellina*. It is 4.1 millimeters long, 3 millimeters high, and about 1.9 millimeters thick. The shell is subovate in outline, and the nonprominent beak is situated well in advance of the mid-length. Impressions on the mold indicate markedly irregular growth lines and undulations.

Cymbophora sp.

(Plate 2, figure 17)

Two medium-sized external molds, one a right (M.C.Z. 15111, unfigured) and the other a left valve (M.C.Z. 15112, figured) appear to belong to an undescribed species of *Cymbophora* Gabb. They are subtrigonal in outline. The larger, the left valve, is approximately 28 millimeters long and 20 millimeters high. The main surface is marked with fine concentric growth lines, with coarser, irregularly spaced growth undulations toward the ventral margin, and with numerous very faint radial lines. The postero-dorsal slope is steep, forming almost a right angle with the plane of contact of the two valves, and the umbonal ridge is marked with strong, coarse growth ridges, each of which seems to be formed by the coming together of several of the small ridges. This form differs from *Cymbophora trigonalis* Stephenson[12] in its steeper postero-dorsal slope, its greater posterior inflation, its finer growth lines, and its apparent lack of coarse growth ridges on the antero-dorsal slope.

A young shell of *Cymbophora* (M.C.Z. 15113) is represented in the collection by both the external and the internal molds. It is only 6 millimeters long and 5 millimeters high, and is marked toward its ventral margin with fine sharp concentric growth lines. The hinge is not completely preserved but appears to be essentially like that of *Cymbophora;* the hinge elements are more attenuated than the corresponding elements of the hinge of *C. trigonalis*. This shell may be the young of the species represented by the larger shells described in the preceding paragraph.

Donax(?) atlantis Stephenson, n.sp.

(Plate 3, figures 1-3)

Description.—Shell of medium size, elongated, depressed, equivalve, strongly inequilateral. Beak broad, moderately prominent, strongly incurved, slightly prosogyrate, situated about two-thirds the length of the shell from the anterior extremity; the greatest inflation is a little back of the beak, above the mid-height, and the shell is strongly compressed anteriorly. The surface is marked by fine growth lines and a few stronger growth undulations and ridges; very fine, faint radiating lines can be detected in places.

Antero-dorsal margin long, nearly straight, gently inclined; anterior margin sharply rounded; ventral margin long and very broadly rounded; posterior margin subangular below, subtruncated above; postero-dorsal margin broadly arched, steeply inclined.

Hinge of right valve incompletely preserved, but exhibits a deep triangular socket below the beak, bordered behind by a narrow cardinal tooth directed downward and backward; back of this cardinal is an oblique, narrow, shallow socket. There is a well-developed, elongated anterior lateral socket with a strong bounding ridge below.

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[12] L. W. Stephenson: *The Cretaceous formations of North Carolina; Part I, Invertebrate fossils of the Upper Cretaceous formations*, N. Car. Geol. and Econ. Surv., vol. 5 (1923) p. 336, pl. 85, figs. 1-6.

A short, rather deep, ligamental groove lies back of the beak. The internal mold reveals well-marked adductor scars, of which the posterior one is large and broadly subovate, and the anterior one smaller and more elongate. The pallial line lies low toward the ventral margin, and the pallial sinus is small, shallow, and subangular at its inner end. The inner margin appears to lack crenulations.

Dimensions of the holotype: Length, 30 millimeters; height, 17 millimeters; convexity, about 4 millimeters.

Remarks.—Although this species is probably not a true *Donax,* its relationships appear to be with the Donacidae. Among the members of this group the hinge is quite variable in the number and strength of its elements; the laterals, for example, may be strong, weak, or absent. Another variable feature is the strength of development of the marginal crenulations; although generally present, they are weak on some species, and on some are practically wanting; on some, they are wanting in the young but appear at some later more adult stage. The small pallial sinus on the Georges Bank species is in contrast to the profound one on most Tertiary and Recent species.

Although there is good reason for regarding this species as belonging to an undescribed genus, the material is hardly sufficiently complete or well enough preserved, to warrant making the species the type of a new genus.

Types.—Holotype, Museum of Comparative Zoölogy, Harvard College, Cambridge, Massachusetts (M.C.Z. 15114). One figured paratype (M.C.Z. 15115). Unfigured paratypes (M.C.Z. 15116, 15117).

Occurrence.—Atlantic Ocean, Georges Bank, Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from depths of 480 to 596 meters.

Corbula sp. (*a*)

(Plate 3, figure 4)

Description.—The description is based on one incomplete external mold of a right valve (M.C.Z. 15118). Shell small, short, moderately and broadly inflated. Beak broad, strongly incurved; antero-dorsal slope very steep; umbonal ridge subangular; postero-dorsal slope steep, slightly excavated. Anterior margin sharply rounded; ventral margin broadly rounded; posterior margin truncated with the nearly straight edge sloping a little forward. Surface ornamented with rather strong round-crested, closely-spaced, concentric ridges separated by sharply incised interspaces, narrower than the ridges.

Dimensions: Length, 4.1 millimeters; height, 3.2 millimeters.

This species is similar in sculpture to *Corbula williardi* Wade,[13] but is less inflated, more elongated, and lacks the pronounced radiating sulcus which is present on that species immediately in front of the umbonal ridge. *C. paracrassa* Wade has a similar, but coarser, type of sculpture, is shorter, more inflated, and has a shallow radiating sulcus in front of the beak.

Corbula sp. (*b*)

(Plate 3, figure 5)

Description.—One external mold of the left valve of a small *Corbula* Lamarck (M.C.Z. 15119), in the matrix surrounding the bryozoan species, *Plethopora americana* Bassler (p. 411), is incomplete only in the lower anterior portion. It is of median length and moderate inflation. Umbonal region broad, beak incurved and prosogyrate; umbonal ridge angular, somewhat sinuous; postero-dorsal slope steep, up-arched, and broadly excavated. Anterior margin sharply rounded; ventral margin nearly straight centrally, curving up somewhat toward the ends; posterior margin truncated with nearly straight edge inclined rather strongly forward. The mold includes a little of the beak and postero-dorsal margin of the right valve; there appears to be a narrow elongated escutcheon, and the slightly upturned edges of the two valves produce a postero-dorsal keel of moderate prominence. The surface is ornamented only with rather fine, somewhat irregular growth lines.

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[13] Bruce Wade: *The fauna of the Ripley formation on Coon Creek, Tenn.*, U. S. Geol. Surv., Prof. Pap. 137 (1926) p. 97, pl. 31, figs. 17 and 18.

Approximate dimensions: Length, 5.5 millimeters; height, 4 millimeters.

Two internal molds of about the same size as the external mold may belong to the same species (M.C.Z. 15120).

The species is closely related to *Corbula monmouthensis* Gardner from the Monmouth formation of Maryland,[14] but it is only about half as large and is less sharply sculptured.

Class Gastropoda

Polinices(*?*) sp.

(Plate 3, figure 6)

Description.—One imperfect external mold of a small naticoid shell (M.C.Z. 27918) is inadequate for certain generic identification. The spire is low, and the conch expands rapidly; the body whorl is plump, and a narrow, shallow sulcus closely borders the suture.

An internal mold of the body whorl of another small naticoid shell (M.C.Z. 27919) is plump just above the periphery and becomes slightly flattish above, toward the suture; it may belong to *Polinices* Montfort. The greatest diameter is 4.4 millimeters.

Unidentified specimens of *Turritella*-like gastropods

(Plate 3, figures 7, 8)

One fragment of the body whorl of a turreted shell (M.C.Z. 27920) probably belongs to the genus *Turritella* Lamarck (Pl. 3, fig. 7). The whorl is about 8 millimeters high. The ornamentation consists of two small closely parallel spiral ribs on the periphery, two stronger ribs midway of the whorl, and a strong rib a little below the suture. The interspace between the peripheral pair of ribs and the median pair is shallow and of moderate width; the interspace between the median pair of ribs and the uppermost rib is broad and relatively deep. The base rounds abruptly in to the columella and bears three weak spiral ribs. The growth lines trend upward and backward to the middle of the broad upper interspace, where they curve strongly forward to the suture.

The external mold of a turreted shell (M.C.Z. 27921), about 30 millimeters high and 10 millimeters in maximum diameter, has the form of a *Turritella* (Pl. 3, fig. 8). The whorls are nearly flat on the sides and nearly smooth, and the sutural depression is narrow and shallow. The periphery is scarcely subangular, and the base rounds in abruptly to the columella.

The external mold of parts of two whorls of a turreted shell (M.C.Z. 27922) is somewhat like the preceding one, but the sides are broadly convex, and the sutural depression is deeper; the largest whorl is 7.7 millimeters high.

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[14] Julia A. Gardner: *Correlation of the Upper Cretaceous formation*, Md. Geol. Surv., *Upper Cretaceous*, (2 vols.) (1916) p. 715, pl. 44, figs. 4-8.

Another internal mold of a turreted shell (M.C.Z. 27923), about 22 millimeters high, exhibits curiously corroded spiral lines which are not parallel to the sutures; it may be a *Turritella*.

Still another internal mold (M.C.Z. 27924), about 16 millimeters high as preserved, is turreted like a *Turritella* and is ornamented with two broad, nonprominent broadly rounded spiral swellings on each whorl, separated by a broad shallow depression; the lower swelling is the stronger; the sutural depression is narrow and only moderately deep.

A fragment of a very much water-worn turreted shell (M.C.Z. 27925), having a maximum diameter of about 6 millimeters, exhibits a broad spiral swelling around the lower two-thirds of the whorl, bordered above by a broad shallow depression; its generic relationship is indeterminate.

Cerithium georgesensis Stephenson n.sp.

(Plate 3, figures 9, 10)

Description.—The description is based on a gutta-percha squeeze of an external mold.

Shell small, slender, with 14 or more closely appressed whorls; protoconch not preserved. Sides of whorls nearly flat. Sutural depression rather broad and shallow. Each of the two larger, well-preserved whorls is ornamented with four moderately prominent primary spiral ribs, and each of the interspaces bears a narrow, weak thread; the spirals are crossed by weak axials, numbering 11 or 12 to half a whorl; the intersections of the axials with the primary spirals are marked by nodes, which are weak on the anterior spiral and increase slightly in strength on the three succeeding spirals above. Faint, broad axial swellings at wide intervals are probably incipient varices. The aperture is not preserved.

Dimensions: Height, 14+ millimeters; diameter, 4+ millimeters.

Remarks.—The ornamentation on this species differs considerably from that on the few previously described Upper Cretaceous species of *Cerithium* from the Coastal Plain.

Type.—Holotype, Museum of Comparative Zoölogy, Harvard College, Cambridge, Massachusetts (M.C.Z. 27926).

Occurrence.—Atlantic Ocean, Georges Bank, Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from depths of 480 to 596 meters.

FOSSILS FROM BANQUEREAU

DISCOVERY, ENUMERATION, AND SIGNIFICANCE

The Cretaceous fossils examined and reported upon by Dall in 1925,[15] mentioned on a previous page, were obtained by Captain Ludwig Olson, of the schooner *William Thomson*, on the eastern part of Banquereau, Nova Scotia, from the bed of the ocean, at a depth of 200 fathoms. The material examined by Dall, consisted of several pieces of indurated, highly fossiliferous, finely arenaceous shell marl, largely made up of shell fragments; about a dozen species of fossils were partly exposed on the surfaces of these pieces. The rock is interpreted to have been a boulder which had been torn loose from its mother ledge by the shove of glacial ice during one of the invasions of Pleistocene time. The recent careful preparation of this material by MacNeil has resulted in the recognition of additional well-preserved specimens, which previously had been concealed within the rock. The following is a revised list of the identifiable organisms thus made available:

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[15] W. H. Dall: *Tertiary fossils dredged off the northeastern coast of North America*, Am. Jour. Sci., 5th ser., vol. 10 (1925) p. 213-218.

Revised list of fossils from Banquereau

- Coelenterata:
  - *Parasmelia*(?) sp.
- Vermes:
  - *Serpula* sp.
- Mollusca (Pelecypoda):
  - *Acila banquereauensis* Stephenson n.sp.
  - *Nuculana piscatoria* Stephenson n.sp.
  - *Breviarca scotiensis* Stephenson n.sp.
  - *Pteria*(?) *dalli* Stephenson n.sp.
  - *Exogyra* sp. (smooth, young individuals)
  - *Exogyra* sp. (costate, young individuals)
  - *Pecten* (*Camptonectes*) *microcancelli* Stephenson n.sp.
  - *Liopistha* sp.
  - *Etea* sp. (aff. *E. carolinensis* Conrad)
  - *Lucina olsoni* Stephenson n.sp.
  - *Isocardia novensis* Stephenson n.sp.
  - *Aphrodina marina* Stephenson n.sp.
  - *Cyprimeria* sp.
  - *Cyclorisma elongata* Stephenson n.sp.
  - *Cyclorisma* sp.
  - *Legumen intermedium* Stephenson n.sp.
  - *Leptosolen* sp. (aff. *L. biplicatus* Conrad)
  - *Corbula latona* Stephenson n.sp.
  - *Corbula tethys* Stephenson n.sp.
- Mollusca (Scaphopoda):
  - *Dentalium* sp. (ribbed)
  - *Dentalium* sp. (small, smooth)
- Mollusca (Gastropoda):
  - *Turritella macneili* Stephenson n.sp.
  - *Turritella thomsonina* Stephenson n.sp.
  - *Anchura pontana* Stephenson n.sp.
  - *Volutoderma*(?) *venusta* Stephenson n.sp.
  - *Avellana pelagana* Stephenson n.sp.
  - Unidentified young gastropods

This list includes one imperfectly preserved coral of the subclass Hexacoralla, questionably referred to *Parasmelia;* fragments of marine worm tubes, probably *Serpula;* at least 16 genera, representing 19 species of pelecypods, 12 described as new and the others unidentified; two unidentified species of scaphopods of the genus *Dentalium;* and at least 7 genera of gastropods, 3 unidentified, representing 8 species, 5 described as new, and the others unidentified. Only 5 genera, *Serpula, Exogyra, Liopistha, Corbula,* and *Turritella*(?), and no species, are common to the Banquereau and Georges Bank lots.

The worm tubes are not diagnostic of the age of the containing rock.

The assemblage of pelecypods is clearly an Upper Cretaceous one, and the species referred to the genera, *Breviarca, Exogyra, Etea, Aphrodina, Cyprimeria, Cyclorisma, Legumen,* and *Leptosolen,* definitely ally the fauna with the Upper Cretaceous series of the Atlantic and Gulf Coastal Plain. The genus *Acila* Adams has not previously been reported from this region, and has generally been looked upon as essentially Pacific in its geographic range, both fossil and Recent; one species of *Acila*, however, which is specifically quite distinct from the Banquereau one, has been recorded from the Upper Cretaceous (Gault) of England.

Although the Woodbine sand of Texas is geographically far distant from Nova Scotia, several elements in the Banquereau fauna are suggestive of an approximate age relationship with a largely undescribed fauna from the upper part of the Woodbine. *Pteria*(?) *dalli*, for example, is very close to a large Woodbine *Pteria*(?); *Cyprimeria* sp. is similar to a species in that formation; *Turritella macneili* and *T. thomsonina* are analogous to one or more noded species in the Woodbine; perhaps the strongest evidence of this age relationship is afforded by *Volutoderma*(?) *venusta*, a volutoid species congeneric with a well-preserved Woodbine species belonging to a section of *Volutoderma* which has not been found in younger beds anywhere in the Atlantic and Gulf Coastal Plain.

There is general agreement that, in terms of the European classification, the Woodbine sand is of Cenomanian age. The Tuscaloosa formation of the eastern Gulf and south Atlantic regions, and the Raritan formation of Maryland, Delaware, and New Jersey, have been correlated with the Cenomanian, but, with the exception of prints of *Ostrea* sp. and *Modiolus* sp., at one locality in the Tuscaloosa of Alabama, no brackish-water or marine faunas have been found in either of these formations; the correlation has been made on the basis of prolific fossil floras studied by E. W. Berry. In view of the probable Cenomanian age of the Tuscaloosa and Raritan formations, the finding of an Upper Cretaceous marine fossil fauna off the coast of Nova Scotia, having affinities with the fauna of the Woodbine, suggests the possibility that the Banquereau rock is a submerged marine representative of the Raritan formation. The Banquereau fauna is, therefore, tentatively correlated with the Cenomanian.

SYSTEMATIC DESCRIPTIONS

Phylum COELENTERATA

Parasmelia? sp.

(Plate 3, figure 11)

The corals are represented in the Banquereau material by one small, very imperfect cone-shaped specimen belonging to the Hexacoralla and suggestive of the genus *Parasmelia* in the family Trochosmiliidae (Yale, Peabody Museum 14801). The ribs are numerous and distinct and alternate in size; they are obscurely beaded as preserved. Dimensions: Height, about 9 millimeters; maximum diameter, 8+ millimeters.

Phylum VERMES

One fragment of a smooth, straight, calcareous tube is 12 millimeters long and 5.5 millimeters in maximum diameter. The tube wall is of moderate thickness, and the nearly smooth surface is marked only with fine growth lines which pass somewhat obliquely around the tube. The tube appears to be that of a *Serpula*. Another similar, but shorter, tube is 6 millimeters in diameter (Y.P.M. 14802).

Three small, sinuous tubes, apparently of *Serpula* (Y.P.M. 14803), are present; one of them is 33 millimeters long and 2.3 millimeters in diameter.

Phylum MOLLUSCA

Class PELECYPODA

Acila banquereauensis Stephenson, n.sp.

(Plate 3, figures 12-14)

Description.—Shell of medium size, thick, subovate in outline, equivalve, strongly inequilateral, greatly elongated anteriorly, moderately convex, greatest inflation a little back of the beak and a little above the mid-height. Beaks small, nonprominent, incurved opisthogyrate, situated far toward the posterior end. Lunule obscure. Escutcheon wide, heart-shaped, extending nearly to the posterior base, bordered by a distinct, subangular ridge which is paralleled within on each valve by a shallow, radiating depression. Antero-dorsal margin long, broadly arched; anterior margin sharply rounded; ventral margin broadly rounded; posterior margin steep, subtruncated but bulging slightly. The hinge is imperfectly preserved, but the taxodont teeth are divided into two series, a long broadly arched anterior one, and a short slightly arched, steeply descending posterior one; the two series appear to be separated by a narrow, triangular chondrophore which trends obliquely forward and a little downward. Inner margin finely crenulated.

The growth lines are fine above, passing below into coarse, irregularly spaced ridges; very fine, obscure radial lines cross the growth lines. The whole surface is further ornamented with a system of fine, closely spaced, irregularly zig-zag ridges, which, though roughly concentric, trend independently of the growth lines; although there is considerable individual variation in the angulations of these ridges, all the available shells exhibit one line of angulations more prominent than the others, situated a little in advance of the mid-length, and directed beakward; this angulation is, however, much less extreme in its upward reach than the similar feature on most other species of *Acila*.

Dimensions of the holotype: Length, 15.9 millimeters; height, 13 millimeters; thickness, 9.4 millimeters.

Remarks.—This is the first recorded occurrence in the Atlantic region of North America of a nuculid shell having a zig-zag type of ornamentation. This ornamentation, although essentially of the same nature as that characterizing the genus *Acila* H. and A. Adams,[16] does not exhibit the extremes of angulation which characterize the typical species of that genus. Although the angulations are more numerous and irregular than on either *Acila, sensu stricto,* or on *Acila* (*Truncacila*) Schenck,[17] those on successive ribs do exhibit a rough beakward alignment. The writer doubts the correctness of classing the so-called divaricate ribs of *Acila* as radial ribs in the usual sense. They appear to be independent of both radial and concentric sculpture.

The living representatives of *Acila* are restricted to the Indo-Pacific region. Although regarded as essentially a Pacific genus, it has been recorded from the Cretaceous (Gault) and from the Pliocene, of England.

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[16] H. and A. Adams: *Generic Record of Molluscs*, vol. 2 (1858) p. 545. Type, *Nucula divaricata* Hinds.

[17] H. G. Schenck, *in* U. S. Grant and H. R. Gale: *Catalogue of the marine Pliocene and Pleistocene Mollusca of California,* San Diego Soc. Nat. Hist., Mem., vol. 1 (1931) p. 115.

The Banquereau material yielded no specimens which are closely related to either *Nucula amica* Gardner or *N. stantoni* Stephenson, as indicated in Dall's published list.

Types.—Holotype (Y.P.M. 14804); one figured paratype (Y.P.M. 14805); four unfigured paratypes (Y.P.M. 14806). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Nuculana piscatoria Stephenson, n.sp.

(Plate 3, figures 15, 16)

Description.—Shell small, elongate, moderately convex, slightly constricted posteriorly, with greatest inflation below the beak well above the mid-height. Antero- and postero-dorsal slopes steep. Beaks broad, moderately prominent, strongly incurved, direct, approximate, situated slightly in advance of the mid-length. Umbonal angle about 130 degrees. Antero-dorsal margin slightly arched; anterior margin sharply rounded above the mid-height; ventral margin broadly rounded, the curve being a little stronger anteriorly than posteriorly; posterior extremity very sharply rounded; postero-dorsal margin long, nearly straight, slightly keeled.

Surface nearly smooth, but faint growth lines and ridges can be detected and these are a little stronger anteriorly than elsewhere.

Dimensions of the holotype, which includes both valves: Length, 6.4 millimeters; height, 4 millimeters; thickness, 3 millimeters; the largest paratype, a right valve, is 7.9 millimeters long and 4.8 millimeters high.

Remarks.—This small, simple, and nearly smooth *Nuculana* appears to be specifically different from any previously described Cretaceous shell of this genus.

Types.—Holotype (Y.P.M. 14807); 5 paratypes (Y.P.M. 14808). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Breviarca scotiensis Stephenson, n.sp.

(Plate 3, figures 17, 18)

Description.—Shell small, of medium thickness, moderately inflated, subquadrate in outline, longer than high, slightly inequilateral, nearly equivalve, the left valve slightly overlapping the right around the ventral and terminal margins. Beaks broad, moderately prominent, incurved, direct, markedly separated, situated about 0.45 the length of the shell from the anterior extremity. Umbonal ridge angular near the beak, becoming rounded to broadly rounded distally. Antero-dorsal slope steep; anterior and ventral slopes rounding down broadly to the margins; postero-dorsal slope steep near the beak, slightly excavated radially, flattening out noticeably toward the rear; greatest inflation below the beak, well above the mid-height.

The hinge is rather narrow, and the numerous taxodont teeth are typical of the genus.

Cardinal area amphidetic, long and narrow, very broadly arched above, straight below; the ligament occupies a small, asymmetrical slightly incised triangular space on the cardinal area below the beak, the base of the triangle being about two-fifths the length of the straight upper margin of the hinge; the ligamental area is striated normal to the hinge line, and is slightly longer back of, than in front of, the beak.

The interior features are concealed by the matrix.

Anterior margin regularly rounded; ventral margin broadly rounded; posterior margin sharply rounded below, truncated and sloping forward above.

The surface is ornamented with rather strong, sharp, closely spaced growth ridges, and by numerous, fine, weak, radiating lines.

Dimensions of holotype, a left valve: Length, 10.2 millimeters; height, 7 millimeters; convexity, 3.1 millimeters. Dimensions of a nearly complete young paratype: Length, 6.8 millimeters; height, 4.8 millimeters; thickness, 3.7 millimeters.

Remarks.—Dall compared this species with *Striarca umbonata* (Conrad), (=*Trigonarca* (*Breviarca*) *umbonata* Conrad),[18] from which it differs in the following respects: The shell is proportionately longer and somewhat less inflated; the umbone is broader, and the postero-dorsal slope less steep; the postero-ventral margin curves upward less strongly; the radial lining is a little more distinct; and the average size is smaller.

In 1923,[19] the writer referred *Trigonarca* (*Breviarca*) *umbonata* Conrad and five other species to the genus *Striarca,* a Maryland Miocene genus. Further consideration has convinced him that differences in form and ornamentation justify the retention of the generic name *Breviarca* Conrad, for the Upper Cretaceous ark shells having transversely striated ligamental areas.

Types.—Holotype (Y.P.M. 14809); 18 paratypes (Y.P.M. 14810). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Pteria(?) *dalli* Stephenson, n.sp.

(Plate 3, figures 19, 20)

Description.—Adult shell large, subtrigonal in outline, thick in the umbonal region, thinning toward the margins, moderately inflated, inequivalve, inequilateral. Beaks only moderately prominent, incurved, strongly prosogyrate, approximate, situated about one-third the length of the hinge line from the anterior extremity. The left valve is noticeably more inflated than the right. The main inflation of each valve extends downward and obliquely backward from the beak; the shell is narrow but round-crested in the umbonal region and expands regularly, becoming more broadly rounded toward the ventral margin; the upper anterior portion of each valve extends forward in the form of a strongly compressed, triangular wing; on right valves, the anterior wing is separated from the main body by a radial, subangular sulcus; the upper posterior portion of the shell expands backward, sloping gently away from the main body, and becoming strongly compressed distally.

Hinge long, straight, and proportionately narrow, reaching a width of 9 or 10 millimeters on very large shells; it is longitudinally striated. In adults the ligament occupies a shallow depression on the hinge extending from just below the beak backward for at least two-fifths the distance to the extremity; the forward end of the ligament is bounded by an oblique line which extends in a gentle slope, from below the beak, backward and downward to the inner margin. On the hinge of one small right valve a series of four elongate-ovate ligamental pits, partly separated from each other, show that in the younger stages the ligament is multivincular; it appears that in later stages these merge to form one long ligament, occupying a continuous shallow pit. Although Cretaceous shells having the form of this species are generally referred to the Recent genus *Pteria* (or its synonym *Avicula*), the multivincular hinge in the young stage throws grave doubts on the correctness of this reference.

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[18] T. A. Conrad: *Descriptions of new genera and species of fossil shells of North Carolina......,* *in* W. C. Kerr: *Report of the geological survey of North Carolina,* vol. 1, Appendix A (1875) p. 3, pl. 1, fig. 8.

[19] L. W. Stephenson: *The Cretaceous formations of North Carolina; Part I, Invertebrate fossils of the Upper Cretaceous formation,* N. Car. Geol. and Econ. Surv., vol. 5 (1923) p. 114, pl. 20, figs. 14-20.

On the inner margin of the hinge of the left valve, 2 or 3 millimeters in front of the beak, is a slightly elongated tooth, which bulges downward below the lower hinge margin; this tooth is set off from the hinge surface above by a narrow, shallow channel, the ends of which are sunken into somewhat deeper socket-like depressions in front of, and behind, the tooth. The corresponding part of the hinge of the right valve is poorly preserved in the available specimens, but there appears to be a socket to receive the tooth of the left valve, and obscure teeth to fit into the depressions at either end of the tooth of that valve.

A pair of small, profoundly excavated muscle scars are situated high up in each valve, just below the beak; the two are quite close together, the posterior one being a little lower than that of the anterior. A row of small, closely spaced pits extends from the anterior one of these scars, in a gentle curve, downward and a little backward; these pits mark the pallial line and are the scars of attachment of muscles connected with the pallial system. The large posterior adductor scar is not uncovered on the available material.

The smooth outer surface of the shell is marked only by fine, obscure growth lines.

The available shells are all too incomplete for accurate measurement. The holotype, a left valve shown in Plate 3, figure 19, has a convexity of about 20 millimeters, and its hinge is at least 75 millimeters long; a fragment of another left valve has a convexity of about 27 millimeters, and a wider hinge than the holotype, and must pertain to a much larger shell.

Remarks.—The exterior of the left valve, shown in Plate 3, figure 19, was exposed on one side of the piece of rock which was examined by Dall, but the hinge was not seen by him; this appears to be the shell which he identified as *Gryphaea vesicularis* Lamarck. In addition to this shell, the rock yielded two other left valves and four right valves of the same species. Only two of the available shells, both left valves, are adults.

A closely related, large, undescribed *Pteria*(?) occurs in the upper part of the Woodbine sand of Tarrant County, Texas. It is not so strongly inflated, and the shallow ligamental pit extends farther forward on the hinge plate; it, too, is multivincular in the young stages.

The holotype of *Pteria*(?) *gastrodes* (Meek), from rocks of Colorado age near Coalville, Utah, appears to be a less opaque species than *P.*(?) *dalli*, but its form has been somewhat altered by mechanical crushing.

Types.—Holotype, a large left valve (Y.P.M. 14811); 8 paratypes, 2 left valves, 4 right valves, and 2 hinge fragments, one large (Y.P.M. 14812). Peabody Museum, Yale University, Connecticut. Named in honor of the late William H. Dall.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Exogyra sp. (smooth)

The collection includes three small, smooth left valves belonging to the genus *Exogyra* Say. The largest (Pl. 4, fig. 1) is badly distorted, having been attached over a proportionately large area to a smooth, broadly curved object, probably another shell (Y.P.M. 14813); it is elongated in the direction of the height (maximum dimension, 23.5 millimeters) and has a strongly curved beak; it might well be the young of any one of several smooth species of *Exogyra.*

The other two shells are much smaller and are not distorted by the scars of attachment, which are very tiny (Y.P.M. 14814); they are proportionately high and narrow and have sharply twisted beaks; their maximum dimensions are respectively 6.8 and 9 millimeters.

Exogyra sp. (costate)

One small left valve (Pl. 4, fig. 2) of an *Exogyra* is finely and regularly costate. It is a strongly inflated shell and has its umbone and posterior slope distorted by attachment to the apical portion of a gastropod (Y.P.M. 14815). This shell may be the young of any one of several species of *Exogyra* whose surfaces are ornamented or partly ornamented with costae. Dimensions: Length, 13 millimeters; height, 12.5 millimeters; convexity, 7 millimeters.

Another left valve, only 8.4 millimeters high, is smooth except in a narrow band adjacent to the ventral margin, where it is distinctly costate. Still another small fragment is costate (Y.P.M. 14816).

Pecten (Camptonectes) microcancelli Stephenson, n. sp.

(Plate 3, figures 21, 22)

Description.—Shell small, moderately thick, subcircular in outline, depressed, convex, subequilateral, slightly inequivalve. Beaks small, nonprominent, direct, situated centrally. Antero- and postero-dorsal slopes low, but steep, meeting the aural surfaces almost at right angles, and forming subangular sulci which diverge from the beak at an initial angle of 83 degrees. Ears incomplete on all specimens, but of moderate size. The byssal sinus at the base of the anterior ear of the right valve forms a sharp notch of medium depth. Interior of shell not uncovered.

Surface of both valves microscopically cancellated with very fine, regular, closely spaced, concentric growth ridges, every fourth, fifth, or sixth one of which tends to be a little stronger than the intermediate ones; the concentric ridges are crossed by still smaller and finer, closely packed, radiating riblets, which curve strongly around to the upper margins as in the typical *Camptonectes.* The concentric ridges number about 15 to the millimeter, and the radiating riblets 28 or 30 to the millimeter. On the ears, both the radiating and the concentric ribs are coarser and stronger than they are on the main body of the shell. Dimensions of the holotype: Length, 7.5 millimeters; height, 7.8 millimeters; convexity, about 1.8 millimeters.

Remarks.—This species differs in its exceedingly fine cancellated ornamentation from any previously described species of *Pecten* from the Cretaceous of the Atlantic and Gulf Coastal Plain.

Type.—Holotype, a right valve (Y.P.M. 14817); three paratypes, two left and questionably a right valve (Y.P.M. 14818). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Liopistha sp.

The genus *Liopistha* Meek is represented in the collection by two fragments, each of which is ornamented with weak to obscure radiating costae, bearing on their crests the scars of the characteristic small tubercles which ornament the ribs of this species. The fragments are inadequate for specific determination. (Y.P.M. 14819.)

Etea sp.

(Plate 4, figures 3, 4)

The genus *Etea* Conrad is represented by one incomplete moderately large right valve and a fragment of another individual. The shell is considerably longer than high, and subovate in outline. Beak broad, nonprominent, incurved, prosogyrate, situated well in advance of the mid-length. Umbonal ridge angular, sharply defined but not prominent. Postero-dorsal slope long, narrow, slightly and broadly excavated.

The hinge is essentially like that of *Etea,* having a strong, oblique, bifid, posterior cardinal tooth, and a short, narrow oblique anterior cardinal, the two separated by a deep, broad, triangular socket; a narrow, deep socket lies back of the posterior cardinal. An anterior lateral, which is, in reality, the strong, short inner element of a pair of asymmetric claspers, has its posterior end crowding closely up under the anterior cardinal, from which it is separated by a deep narrow slit; the outer clasper is weakly developed and is deeply submerged below the margin of the shell; the two claspers are separated by a deep, short socket. The ligamental groove is short and narrow and is bordered below by a narrow nymph. The posterior lateral is broken away. (Y.P.M. 14820.)

Lucina olsoni Stephenson, n. sp.

(Plate 4, figures 5, 6)

Description.—Shell small, subcircular in outline, moderately inflated for the genus, equivalve, slightly inequilateral. Beaks small, moderately prominent, incurved, approximate, slightly prosogyrate, situated a little back of the mid-length. Umbonal ridge obscure but recognizable. Greatest inflation below the beak, well above the mid-height; antero-dorsal slope steep; postero-dorsal slope less steep, slightly and broadly excavated radially.

Hinge of left valve with a deep triangular socket below the beak; anterior cardinal tooth thick, moderately prominent, directed downward and a little forward, bordered in front by an obscure narrow socket; posterior cardinal small, narrow, obscure; anterior claspers distant, short, separated by a moderately deep socket; posterior claspers similar to the anterior pair but a little more distant. Hinge of right valve not well exposed in the available material.

Ligament proportionately long, moderately deep, bordered below by a narrow nymph. Lunule short, broad, deeply excavated, more sharply outlined on the left than on the right valve. Escutcheon wanting.

Inner margin finely crenulated. Posterior adductor scar small and high in the shell; anterior adductor elongated downward and slightly separated from the pallial line below, as is characteristic of the genus. Pallial line simple.

Antero-dorsal margin gently arched, inclined; anterior margin obtusely sub-angulated; ventral margin regularly rounded; posterior margin subtruncated; postero-dorsal margin short, slightly arched.

The surface is marked with rather coarse, somewhat irregular concentric depressions representing resting stages, with intermediate fine growth lines, and by numerous faint to obscure, fine radial lines.

Dimensions of the holotype: Length, 6.8 millimeters; height, 6.7 millimeters; thickness, 4 millimeters.

Types.—Holotype, a nearly complete individual (Y.P.M. 14821); one figured paratype (Y.P.M. 14822); 32 unfigured paratypes (Y.P.M. 14823). Peabody Museum, Yale University, New Haven, Connecticut. Named in honor of Captain Ludwig Olson.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Isocardia novensis Stephenson, n.sp.

(Plate 4, figures 7, 8)

Description.—Shell of medium size, thin, subtrigonal in outline, strongly inflated, narrow in the umbonal region, inequilateral. The greatest inflation appears to be at about the mid-length, a little above the mid-height. Beak prominent, strongly incurved, strongly prosogyrate, the apex twisted well back away from the dorsal margin, situated about one-fifth the length of the shell from the anterior extremity. Antero-dorsal margin slightly arched, steeply inclined; anterior margin sharply rounded; ventral margin broadly rounded; posterior margin subtruncated below, rounding above into the broadly arched postero-dorsal margin. There is a narrow escutcheon of moderate length, bounded on the outer side by a sharply impressed line. No lunule is present.

The otherwise smooth surface is covered with fine, closely spaced growth lines of somewhat irregular development.

The hinge elements are irregular and distorted in a manner characteristic of the genus. The anterior cardinal of the left valve is long, gently arched, and lies along the lower margin of the hinge; the under side is indented near the forward end by a shallow pit or socket; this tooth is paralleled above by a longer, narrow, deep socket. The posterior cardinal tooth is long, narrow, and gently arched over the posterior end of the long socket just described; the tooth is paralleled above by a long, narrow channel of only moderate depth. The arched dorsal margin of the shell is thin and prominent. The ligamental groove is very narrow and deep.

The interior of the shell is not uncovered.

The six specimens in the collection are distorted by mechanical compression, and exact measurements are impossible. A plus sign is used to indicate that the compression has acted to shorten the given dimension, and a minus sign shows the reverse condition

Dimensions of the holotype: Length, 23.4— millimeters; height, 21— millimeters; convexity, 11.6+ millimeters. One of the paratypes is somewhat larger than the holotype, and the others are considerably smaller.

Remarks.—The strong inflation, prominent beak, and posterior subtruncation serve to distinguish this shell from *Isocardia cliffwoodensis* Weller, from the Magothy formation near Matawan, New Jersey. It is also larger and proportionately shorter and higher than that species.

Types.—Holotype, a left valve (Y.P.M. 14824); 5 paratypes, 2 left valves, and 3 right valves (Y.P.M. 14825). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Aphrodina marina Stephenson, n.sp.

(Plate 4, figures 9-12)

Description.—Shell small for the genus, broadly subovate in outline, moderately convex, equivalve, inequilateral. Beaks moderately prominent, strongly incurved, approximate, prosogyrate, situated about one-third the length of the shell from the anterior extremity. Lunule broad, moderately long, sharply outlined by an impressed line; escutcheon wanting. Greatest inflation about midway of the length and somewhat above the mid-height, from which point the surface slopes broadly and regularly to the terminal and ventral margins; the steepest slopes are in front and back of the beak.

The hinge appears to be essentially like that of the typical *Aphrodina* Conrad. The right valve exhibits the characteristic, long, oblique, strongly bifid, posterior cardinal tooth, with a rather wide, deep, triangular socket in front of it; the median cardinal is thick and prominent, and is separated from the thin but fairly prominent, nearly direct anterior cardinal by a profound, narrow, triangular socket; the roughened anterior claspers lie close in front of the anterior cardinal, on a platform of moderate width. The hinge of the left valve is seen only in young individuals, but the anterior cardinal tooth at its inner end shows the initial bifurcation which becomes more strongly developed in the adults of the genotype, *A. tippana* Conrad; the median cardinal is short and moderately thick and is directed a little backward; the posterior cardinal is long, thin, and strongly oblique; the three cardinals are separated by deep sockets. The anterior lateral tooth is short and distinctly roughened by striations even in young individuals.

Ligamental groove long and moderately deep. The impression of a moderately deep, steeply ascending, pallial sinus is partly uncovered on the internal mold of one individual. The other internal features are not clearly exposed.

The surface is closely crowded with sharp, irregular growth ridges, and rather closely crowded, gentle undulations indicate a rapid alternation of vigorous growth and resting stages.

Approximate dimensions of the holotype, a nearly complete but slightly distorted shell: Length, 30.4 millimeters; height, 23 millimeters; convexity, 14 millimeters. The largest paratype, an imperfect right valve, is 25 millimeters high.

Remarks.—The species resembles *Aphrodina tippana* Conrad, from the Ripley formation of Mississippi, but the average size is much smaller, and the surface is more strongly roughened by the growth ridges and undulations. *A. regia* Conrad, from the Snow Hill marl member of the Black Creek formation of North Carolina, attains a much greater size, reaching a maximum length of nearly 90 millimeters; it is smoother at the corresponding stage of growth, but becomes strikingly roughened in its later stages.

Types.—Holotype (Y.P.M. 14826); 1 paratype, figured for the left hinge (Y.P.M. 14827); 2 paratypes used for drawing of right hinge (Y.P.M. 14828); 11 paratypes not figured (Y.P.M. 14829). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Cyprimeria sp.

(Plate 4, figure 13)

The genus *Cyprimeria* is represented by seven incomplete specimens, three of left valves, three of right valves, and an individual with the two valves slightly separated so that the left hinge is partly exposed (one figured shell, Y.P.M. 14830; six unfigured shells, Y.P.M. 14831). The shell is strongly compressed and is broadly subovate to almost subcircular in outline. Beaks small, compressed, nonprominent, scarcely rising above the dorsal margin, prosogyrate, and apparently situated somewhat in advance of the mid-length. The surface in proximity to the beak is marked with fine, sharp, regular, concentric growth ridges; away from the beak the growth lines are fine and more or less irregular. The hinge of the left valve is sufficiently exposed on the one shell just mentioned to show that it is a typical *Cyprimeria*.

The available specimens are probably all juvenile. In outline and form, they are similar to an undescribed species from the Woodbine sand of Texas, which attains a length of 53 millimeters, and a height of 50 millimeters. The Banquereau shells are, however, too small and too imperfect to permit satisfactory identification.

The figured left valve is approximately 21.5 millimeters high, but the largest fragment represents a shell which probably was 35 millimeters high.

None of the specimens suggests the large species, *Cyprimeria gabbi* Stephenson, with which Dall compared part of the Banquereau shells.

Cyclorisma elongata Stephenson, n.sp.

(Plate 4, figures 14-16)

Description.—Shell thin, of medium size, subovate in outline, longer than high, moderately inflated, equivalve, inequilateral. Beaks small, moderately prominent, incurved, approximate, prosogyrate, situated about 0.45 the length of the shell from the anterior extremity. Antero- and postero-dorsal slopes steep near the beak; greatest inflation below the beak, above the mid-height; umbonal ridge wanting.

On the left valve the hinge platform is deeply submerged; the anterior cardinal is thin, slightly curved around toward the front below, and rises high above the platform; median cardinal, thinner and less prominent than the anterior one, from which it is separated by a profound, triangular socket; posterior cardinal long, thin, weak, strongly oblique, slightly arched, lying close under the nymph, from which it is separated by a narrow, shallow channel; a long, oblique triangular socket separates the median and the posterior cardinals. Lateral teeth wanting. Hinge of right valve not clearly exposed, but the strongly bifid posterior cardinal of the genus is apparent.

Ligamental groove long and moderately deep. Nymph narrow, prominent. Lunule and escutcheon wanting. Internal features of the shell not exposed.

Antero-dorsal margin nearly straight near the beaks, becoming arched anteriorly, the margins of the two valves forming a sharp keel; anterior margin rather sharply, but regularly rounded; ventral margin broadly rounded; posterior margin regularly and rather sharply rounded somewhat below the mid-height; postero-dorsal margin long and broadly arched.

Surface marked with fine sharp growth lines of irregular strength.

Dimensions of the holotype: Length, 24.5 millimeters; height, 17.3+ millimeters; thickness, 9.3+ millimeters. The largest paratype, a left valve, is about 38 millimeters long.

Remarks.—This species is much more elongated than the genotype *Cyclorisma carolinensis* (Conrad), from the Snow Hill marl member of the Black Creek formation in North Carolina. The hinge, as seen in the left valve, appears to be essentially like that of the Carolina species.

Types.—Holotype, a somewhat imperfect and partly crushed shell, including both valves (Y.P.M. 14832); 1 crushed paratype, a left valve figured for hinge (Y.P.M. 14833); 3 more or less incomplete and crushed paratypes (Y.P.M. 14834). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Cyclorisma(?) sp.

The collection includes one small, smooth, moderately convex pelecypod with the two valves intact (Y.P.M. 14835), which may be a young individual of the genus *Cyclorisma* Dall. A very faintly and obscurely outlined lunule can be detected with a lens in a good light. The prodissoconch is preserved, but is corroded; it is apparently smooth and of about the same proportions as the later stages of the shell. This shell is also similar in form to *Tenea* Conrad, but, without knowing its hinge character, its true generic affinity can not be determined. The dimensions are: Length, 3.6 millimeters; height, 3.4 millimeters; thickness, 2.1 millimeters.

Legumen intermedium Stephenson, n.sp.

(Plate 4, figures 17-19)

Description.—Shell of medium size, thin, elongate-subelliptical in outline, laterally compressed, equivalve, strongly inequilateral. Beaks small, broad, nonprominent, incurved, approximate, prosogyrate, situated about one-fifth the length of the shell from the anterior extremity.

Hinge of left valve with three cardinal teeth of unequal length; anterior cardinal thin, prominent, directed downward and slightly forward, bounded behind by a profound triangular socket, and in front by a deeply submerged hinge platform; median cardinal prominent, very thin, longer than the anterior one, directed downward and obliquely backward, separated from the posterior cardinal by a profound narrow socket; posterior cardinal long, thin, strongly oblique, separated from the sharp shell margin above by a narrow, relatively shallow channel or socket. Hinge of right valve with the prominent anterior and median cardinals separated by a deep narrow triangular socket, the former bounded in front by a shallow hinge platform. Median cardinal separated from the posterior cardinal by a wider, longer, deep, oblique, triangular socket. Posterior cardinal long, very oblique, narrow but apparently bifid, bounded above by a narrow, moderately deep socket. Lateral teeth wanting.

Ligamental groove short, narrow, moderately deep, bounded below by a narrow nymph. Neither lunule nor escutcheon present.

Pallial sinus moderately deep, rising rather steeply. Other internal features not well exposed.

Antero-dorsal margin short, slightly arched, steeply inclined; anterior margin sharply rounded at about the mid-height; ventral margin long, very broadly rounded; posterior margin sharply rounded at or a little below the mid-height; postero-dorsal margin long, nearly straight anteriorly, rounding down gently toward the rear.

Surface covered with numerous, sharply developed, irregular growth ridges which become a little coarser toward the ventral margin.

Approximate dimensions of the holotype: Length, 37 millimeters; height, 18.5 millimeters; thickness, 7+ millimeters; one paratype is larger than the holotype.

Remarks.—This shell is intermediate in outline between the greatly elongated *Legumen concentricum* Stephenson and the proportionately shorter and higher *L. carolinense* (Conrad), both of which occur in the Snow Hill marl member of the Black Creek formation in North Carolina; it is more finely sculptured than either of these species.

Types.—Holotype, a mechanically crushed incomplete individual with both valves present (Y.P.M. 14836); one incomplete paratype, a left valve with the cardinal dentition well preserved, figured for hinge (Y.P.M. 14837); one incomplete paratype, a right valve with the cardinal teeth somewhat damaged, not figured (Y.P.M. 14838). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Leptosolen sp.

The genus *Leptosolen* Conrad is represented by two incomplete left valves.

The largest specimen (Pl. 4, fig. 20), which is badly crushed, has a length of 27+ millimeters, and a height of 13 millimeters (Y.P.M. 14839). The shell is thin, has the characteristic form and outline of *Leptosolen biplicatus* Conrad, and is closely related to that species. A portion of the shell, scaled off from the underlying matrix near the anterior end of the specimen as preserved, reveals the internal rib or buttress which is characteristic of the genus; this rib is strong, U-shaped in cross-section, and extends from below the beak, downward and slightly backward, nearly to the ventral margin. The surface is covered with fine, sharp, somewhat irregular growth ridges which reveal the characteristic vertical subtruncation of the posterior end.

The other specimen, though very imperfect, is more complete at the anterior end, which is proportionately short and sharply rounded (Y.P.M. 14830). The dimensions are: Length, 12+ millimeters, height, 6.5+ millimeters.

Corbula latona Stephenson, n.sp.

(Plate 5, figures 1-3)

Description.—Shell small, thick, trigonal in outline, moderately inflated, inequilateral, inequivalve, the right valve larger than, and overlapping the margins of, the left valve. A narrow, sharply defined, carina-like umbonal ridge extends from the beak in a sinuous trend to the posterior extremity. The postero-dorsal slope back of the umbonal ridge is narrow, and forms a shallow depression extending from the beak to the extremity; antero-dorsal slope steep. Beaks prominent, strongly incurved, approximate, prosogyrate, situated about two-fifths the length of the shell from the anterior extremity. The greatest inflation is below the beaks and above the mid-height; the posterior part of the shell is narrow, compressed, and pointed.

Hinge only partly revealed, but apparently normal for the genus.

Antero-dorsal margin broadly arched, curving down regularly into the rather sharply rounded anterior margin; ventral margin broadly rounded centrally, becoming slightly excavated posteriorly; posterior extremity acutely angular; a short posterior truncation slopes strongly forward, meeting the straight, steeply inclined postero-dorsal margin at a very broad obtuse angle.

Umbonal area smooth, passing below first into fine, and then into successively coarser and sharper, concentric ridges; the right valve is more distinctly ribbed than the left. The right valve of the holotype exhibits fine, obscure radial lines; among the paratypes the same radial lining may be seen on some right and some left valves, but this feature is apparently variable and may be wanting.

Dimensions of the holotype, a complete individual: Length, 9 millimeters; height, 6.1 millimeters; thickness, 5 millimeters. Some of the less complete paratypes are slightly larger than the holotype.

Remarks.—The species is related to *Corbula subradiata* Gardner from the Monmouth formation of Maryland, but is larger, proportionately more elongated and pointed, and is less distinctly marked radially. The species is similar in form to *C. kanabensis* Stanton from beds of Colorado age 350 feet above the base of the Cretaceous section in upper Kanab Valley, southern Utah, but is smaller, more pointed, and more coarsely marked concentrically.

Types.—Holotype (Y.P.M. 14841); 1 figured paratype, a left valve (Y.P.M. 14842); 27 paratypes, unfigured (Y.P.M 14843)

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl from a depth of 200 fathoms.

Corbula tethys Stephenson, n.sp.

(Plate 5, figures 4-7)

Description.—Shell small inequilateral, inequivalve, strongly inflated centrally and anteriorly, greatest inflation below the umbone and above the mid-height, strongly compressed posteriorly. Beaks prominent, strongly incurved, slightly prosogyrate, slightly overhanging the hinge, situated a little in front of the mid-length; beak of right valve much more prominent than that of left valve. On the right valve a shallow, ill-defined radial sulcus extends from back of the beak, backward and downward to the lower posterior extremity, and marks the dividing zone between the inflated part of the shell and the posterior compressed part. The right valve is much larger than the left valve, which it overlaps on all margins. The antero-dorsal slopes of both valves are steep. The left valve lacks a posterior radiating sulcus. Lunule and escutcheon are wanting.

Antero-dorsal margin arched; anterior margin sharply rounded; ventral margin broadly rounded, rising toward the rear and on the right valve becoming slightly sinuous near the extremity; posterior margin of right valve truncated, short, with obtuse subangles below and above; posterior extremity of left valve rather sharply rounded; postero-dorsal margin nearly straight.

Surface of right valve ornamented with numerous, moderately prominent, round-topped concentric ribs of irregular strength, becoming coarser ventrally, separated by round-bottom interspaces, which range from a little wider to a little narrower than the ribs; the ribs die out completely on the strongly compressed posterior portion of the shell, where only growth lines are present; just above the ventral margin the ribs number three to the millimeter, and midway of the shell, four to the millimeter. The surface of the left valve lacks the prominent ribs, and bears only distinct growth ridges.

Dimensions of the holotype: Length, 4.5 millimeters; height, 3.2 millimeters; thickness, 2.7 millimeters; a larger right valve (Pl. 5, fig. 7) measures: Length, 5.2 millimeters; height, 3.7 millimeters; convexity, 1.9 millimeters.

Remarks.—This species belongs in a subgroup of inflated Corbulas typified by *C. crassiplica* Gabb, the distinguishing characters of which are a strongly sculptured right valve, and a smaller, nearly smooth left valve. The concentric ribbing of the present species is similar to that of *crassiplica* but is much finer.

Types.—Holotype, a medium-sized, slightly incomplete individual, selected because both valves are present (Y.P.M. 14844); 1 paratype, an average size left valve (Y.P.M. 14845); 19 paratypes, not figured (Y.P.M. 14846). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Class Scaphopoda

Dentalium sp. (ribbed)

(Plate 5, figures 8-10)

The description is based on seven fragments which appear to be conspecific. The tube is gently curved, with the strongest curvature toward the smaller end (three figured fragments, Y.P.M. 14847; four unfigured fragments, Y.P.M. 14848). The smallest fragment has a minimum diameter of one millimeter and bears 12 longitudinal, low, narrow, sharp primary ribs separated by wider, nearly flat-bottomed interspaces; several fine, obscure secondary riblets make their appearance between the major ribs, at differing distances from the small end, and increase somewhat in strength away from that end. The larger fragments show that the ribs become progressively weaker toward the larger end, near which the tube is nearly smooth. The largest fragment is 18 millimeters long and has a maximum diameter of 4.7 millimeters. The maximum thickness of tube wall is slightly in excess of half a millimeter.

This species appears to be closely related to a ribbed *Dentalium* from the Woodbury clay of New Jersey. Fragments of tubes from that formation near Haddonfield have 12 to 14 sharp ribs somewhat more distinct than on the Banquereau specimens, but the resemblance is close. Weller[20] identified specimens from the Woodbury clay, including some from near Haddonfield, with *Dentilium subarcuatum* Conrad, the type of which came from near New Egypt, New Jersey,[21] and is probably of Eocene age. The latter is a slender internal mold which shows no external ribbing and can scarcely be said to exhibit specific characters; it is probably specifically distinct from the Haddonfield specimens.

Dentalium sp. (smooth)

(Plate 5, figures 11, 12)

The collection includes two incomplete tubes (Y.P.M. 14849) of a small smooth *Dentalium* which is closely related to *D. leve* Stephenson[22] and to *D. pauperculum* Meek and Hayden,[23] the former from the Snow Hill marl member of the Black Creek formation in the Carolinas, and the latter from the Fox Hills sandstone of the Western Interior.

The tube is slender, slightly arched, tapering gradually but faintly swollen centrally, noticeably compressed in the dorso-ventral diameter, thus producing a broadly ovate cross-section. Growth lines fine and oblique.

Dimensions of largest specimen, which is incomplete at both ends: Length, 6.5+ millimeters; diameter at small end, 0.9 millimeter; diameter at large end, 1.4 millimeters.

These shells appear to be more nearly like *D. pauperculum* than *D. leve,* but are more strongly compressed and taper a little more rapidly than either of those species.

Class GASTROPODA

Turritella macneili Stephenson, n.sp.

(Plate 5, figure 13)

Description.—Shell of medium size for the genus. Spire high, with apical angle of approximately 17 degrees. Whorls 14 or 15 (estimated), very broadly convex on the sides, closely appressed. Suture moderately impressed. The growth lines trend upward and a little backward to a little above the mid-height of the whorl, thence they swing around and extend obliquely forward and upward to the upper suture. Protoconch not preserved.

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[20] Stuart Weller: *A report on the Cretaceous paleontology of New Jersey, based upon the stratigraphic studies of George N. Knapp,* N. J. Geol. Surv., Paleontology, vol. 4 (1907) p. 661, pl. 75, figs. 1 and 2.

[21] T. A. Conrad: *Descriptions of new fossil shells of the United States,* Philadelphia Acad. Nat. Sci., Jour., 2d ser., vol. 2 (1853) p. 276, pl. 24, fig. 13.

[22] L. W. Stephenson: *The Cretaceous formations of North Carolina; Part I, Invertebrate fossils of the Upper Cretaceous formations,* N. Car. Geol. and Econ. Surv., vol. 5 (1923) p. 351, pl. 88, figs. 1-3.

[23] F. B. Meek and F. V. Hayden: *Descriptions of new organic remains from the Tertiary, Cretaceous, and Jurassic rocks of Nebraska,* Philadelphia Acad. Nat. Sci., Pr., vol. 12 (1860) p. 178.

The body whorl is ornamented with 8 primary spiral ribs, the lower and upper ones being rather weak; each spiral bears small, regularly spaced blunt-topped nodes, which number about 14 to the centimeter. The interspaces range from narrower to wider than the ribs and bear fine thread-like secondaries of uneven strength, numbering 2 to 4 according to the width of the space. The number of the spiral ribs and the strength of the nodes decrease progressively toward the apex, the nodes practically disappearing on the sixth whorl from the aperture, and the primary ribs numbering only 3 on the smallest of the 9 preserved whorls; the secondary ribs have practically disappeared on this smallest whorl.

The perimeter of the body whorl is obtusely subangular, and the base is broadly rounded and ornamented with 5 or 6 rather narrow spirals which are not very well preserved.

The aperture is partly broken away but appears to be broadly subovate.

Dimensions of the incomplete holotype: Height, 36+ millimeters; diameter, 9.3+ millimeters.

Remarks.—This species is related to an undescribed nodose species of *Turritella* from the upper part of the Woodbine sand of Tarrant County, Texas.

Type.—Holotype (Y.P.M. 14850). Peabody Museum, Yale University, New Haven, Connecticut. Named in honor of F. Stearns MacNeil.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Turritella thomsonina Stephenson, n.sp.

(Plate 5, figure 14)

Description.—Shell of medium size, with a spiral angle of approximately 16 degrees as measured on the larger whorls. Five of the larger whorls are preserved on the holotype and 6 on the largest paratype; the estimated number of whorls is 18 or 20; the largest whorl on the holotype is nearly flat to slightly concave on the side, and the other smaller ones are very broadly and gently convex. Suture only slightly impressed. Protoconch not preserved. The growth lines curve broadly and rather strongly backward from the lower suture to a little above the mid-height of the whorl, thence they curve strongly forward, but bend noticeably upward before reaching the upper suture.

Each whorl of the holotype bears 5 primary spirals, of which the lowest is weak and nearly smooth; the second is stronger and nearly smooth; the third is about as strong as the second and is weakly nodose; the fourth is the strongest of all and distinctly nodose; and the fifth, though not quite so strong as the fourth, is more distinctly nodose; the nodes number 10 to 12 to the centimeter. The development of the nodes is variable on different individuals; one of the paratypes has strong nodes on all the primaries. The number of primaries is reduced to 3 on the smallest paratype. Of the 4 interspaces, the lowest is the narrowest, the upper next in width, and the other 2 of about equal width; the bottoms of the interspaces bear spiral threads of somewhat unequal strength, ranging in number from 2 to 5 according to the available space. The primary spirals become smoother and weaker on the successively smaller whorls. The base of the body whorl is nearly flat to broadly rounded and bears numerous obscure fine spiral threads. The aperture is broken away.

Dimensions of the holotype as preserved: Height, 25.7+ millimeters; greatest diameter, 11.2 millimeters. The smallest paratype, an apical fragment which stops a little short of the protoconch, has a minimum diameter of less than a millimeter.

Remarks.—This species has flatter sides, fewer primary spirals, and shallower sutures, than has *T. macneili.* It, also, is related to the undescribed nodose species in the Woodbine sand of Texas.

Types.—Holotype (Y.P.M. 14851); 4 incomplete paratypes (Y.P.M. 14852). Peabody Museum, Yale University, New Haven, Conn.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a trawl by the fishing schooner *William Thomson,* from a depth of 200 fathoms.

Anchura pontana Stephenson, n.sp.

(Plate 5, figures 15, 16)

Description.—Shell of medium size. Spire elongate-conical, apical angle about 36 degrees. Whorls 7 or 8 (estimated), broadly convex on the sides closely appressed. Suture deeply impressed. Protoconch not preserved. The axials are strong but somewhat variable, thick, round-crested, nearly direct, and number 17 on the penultimate whorl of the holotype, 12 on the antepenultimate whorl, and 11 on the next smaller whorl; the interspaces are wider than the ribs.

The surface is further ornamented with fine revolving primary spirals, which number 13 or 14 on the penultimate whorl, and most of the interspaces bear one or two very fine thread-like secondary lirae; both the primaries and the secondaries override the axials. The axials are least regular in spacing and strength on the body whorl, being locally small, numerous, and close together; approaching the outer lip, the axials tend to fade out at their lower ends, and the last 5 or 6 of them end 6 or 7 millimeters below the suture; these short axials bear obscure nodes near their lower ends; these nodes are in line with, and form the beginning of, a subangular ridge which extends from the body whorl out onto the upper part of the expanded outer lip. The body whorl is completely covered with primary spiral ribs, separated by interspaces of irregular width each bearing from one to four secondary riblets, the number depending upon the width; both the primaries and the secondaries diverge fan-like and become coarser as they pass out onto the expanded outer lip. The crossing of the spirals and growth ridges produces a finely cancellated pattern on the lower posterior part of the outer lip. The body whorl is broadly rounded on the perimeter and becomes strongly constricted at the base.

Aperture lens-shape in outline, with a shallow, anal canal at the rear, and passing anteriorly into a narrow, straight canal of undetermined length. Outer lip broadly expanded and grossly thickened at its outer edge. The anterior part of the shell and the lower part of the outer lip are broken away but there is at least one shallow, fluted indentation on the lower border of the lip. The broken upper corner of the lip doubtless marks the place of attachment of a narrow upward-curving projection of undetermined length. The ridge, previously mentioned, which extends from the body whorl out onto the upper part of the lip, curves upward toward its end as preserved, and doubtless extended out onto the missing projection. The outer lip between this projection and the spire flares strongly outward and backward, producing a very broad notch; the upper end of the lip rises on the penultimate whorl nearly to its upper suture. Inner lip forming a thin wash of callus, which spreads forward over the parietal wall, and through this callus is reflected the axial and spiral ornamentation; the callus becomes noticeably thicker below, on the lower portion of the columella.

Dimensions of the incomplete holotype: Height, 34+ millimeters; maximum diameter of the body whorl exclusive of the outer lip, 17.5 millimeters.

Types.—Holotype (Y.P.M. 14853); 4 paratypes, all incomplete (Y.P.M. 14854). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Volutoderma(?) *venusta* Stephenson, n.sp.

(Plate 5, figures 17, 18)

Description.—Shell large, thick, volutiform. Spire of medium height, with spiral angle of approximately 43 degrees. Whorls 5 or 6 closely appressed, moderately convex on the sides. Suture deeply impressed. Protoconch not preserved. Body whorl large, elongated, with a moderately wide, slightly excavated, steeply sloping shoulder, which is limited below by a wide subobtuse angle; body flattened below the shoulder, passing below into the very broadly rounded, gently sloping base. The body whorl is incomplete anteriorly.

The posterior part of the body whorl is ornamented with 5 or 6 thick, slightly sinuous, broadly round-crested axials with wider interspaces; these axials are coarsely nodose at the shoulder angle, die out abruptly on the shoulder above, and fade out more gradually about half way down the basal slope below; anteriorly on the body whorl the axials merge into irregularly developed growth lamellae which become quite coarse in a subvaricose band, 8 millimeters wide, bordering the aperture. Passing backward from the body whorl the shoulder angle lies at about the vertical center of the exposed portion of the whorls of the spire. The coarsely nodose axials number 10 on the penultimate whorl and 8 on the antepenultimate.

The body whorl, from the shoulder downward, is ornamented with regularly spaced, low, flattish-topped spiral ribs, which, near the aperture, are narrower than the interspaces, but which converge slightly as they pass toward the rear; the shoulder bears 7 or 8 smaller, more closely spaced spirals, which, however, fade out and disappear before reaching the aperture. Four or five of the spirals below the shoulder are exposed on the penultimate and antepenultimate whorls.

Aperture elongate-lanceolate, modified at the rear by a broad, deep notch which lies well below the suture just above the shoulder angle; anteriorly the aperture passes into a narrow, slightly sinuous canal which is partly broken away. Outer lip broadly curved, thin at the edge, thickening quickly backward; the spiral ribs are faintly reflected on the inner margin of the outer lip. Inner lip very broadly excavated, and forming a thin wash of callus over the parietal wall; a large, thick hump of callus lies at the upper end of the inner lip, just in front of the axial notch. The columella is slightly curved anteriorly; it bears three broadly rounded folds which lie a little above its mid-height; only the termini of these folds are exposed, but they appear to be of about equal strength.

Dimensions of the incomplete holotype: Height, 66+ millimeters; diameter, 30 millimeters.

Remarks.—This species is referred only provisionally to *Volutoderma;* it possesses characters, notably its shorter spire and the deep anal notch on the shoulder, which may justify its assignment to a separate genus. The species is apparently congeneric with an undescribed gastropod in the upper part of the Woodbine sand of northeastern Texas, several good specimens of which are available for comparison at the United States National Museum, in the collections of the United States Geological Survey.

Types.—Holotype (Y.P.M. 14855); 2 incomplete paratypes (Y.P.M. 14856). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean, on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

Avellana pelagana Stephenson, n.sp.

(Plate 5, figures 19, 20)

Description.—Shell of medium size, rotund, broadly rounded over the apex. Spire very low. Protoconch not well preserved. Whorls 3½, closely appressed, expanding rapidly; sides of whorls broadly rounded. Suture slightly impressed. Body whorl broadly and regularly rounded, uniformly ornamented with about 26 regular, low, round-crested, faintly punctate spiral ribs, separated by narrower, punctate interspaces, the punctate markings are fine and obscurely preserved and do not show in the figures; 5 or 6 of the ribs are exposed on the penultimate whorl.

Aperture subcrescentic, acutely subangular at the rear, where it is narrowly channeled, moderately wide in the central part, sharply but regularly rounded at the front. Outer lip thick, regularly varicose, the posterior end of the varix rising a little above the suture; inner margin smooth. Inner lip, broadly excavated anteriorly, forming a thin callus which spreads noticeably forward on the parietal wall, connecting at each end with the varix of the outer lip. Columella bearing three narrow, prominent, round-crested, nearly horizontal folds, the posterior one of which is a little the weaker.

Dimensions of the holotype: Height, 17.8 millimeters; diameter, 14.3 millimeters.

Remarks.—This species is not closely related to any of the four or five species of the genus previously described from the Upper Cretaceous deposit of the Atlantic Coastal Plain.

Type.—Holotype (Y.P.M. 14857). Peabody Museum, Yale University, New Haven, Connecticut.

Occurrence.—Atlantic Ocean on the eastern part of Banquereau, Nova Scotia; from a loose boulder brought up in a fisherman's trawl, from a depth of 200 fathoms.

UNIDENTIFIED YOUNG OF GASTROPODA

(Plate 5, figures 21-23)

A small, young shell (Pl. 5, figs. 21, 22) which includes a smooth, trochoid protoconch, followed by a rapidly expanding body whorl, has not yet been placed in its proper family and genus (Y.P.M. 14858). It may belong in the family Acteonidae. The protoconch has three whorls, the initial one flattened and slightly submerged. The body whorl is broadly rounded over the periphery, becoming sharply constricted below, and is covered with closely packed fine spiral threads. The aperture is almost semi-lunar, with a broadly arched thin outer lip and a short deep anterior canal. The inner lip is deeply excavated midway of the height and forms a thin callus over the parietal wall. The columella bears two distinct folds, the lower one of which lies a little above the upper edge of the anterior canal. The shell is 4 millimeters high and 2.8 millimeters in diameter.

Another rather poorly preserved young shell is trochoid in form and appears to be related to the genus *Monodonta* (Y.P.M. 14859). The body whorl bears 7 or 8 low, regular spirals. The dimensions are: Height, 3 millimeters; diameter, 3 millimeters.

Still another young shell (Pl. 5, fig. 23) is characterized by pronounced spiral sculpture (Y.P.M. 14860). The protoconch is not preserved. The spiral angle is approximately 45 degrees. The body whorl above the base is ornamented with three strong, narrow spirals, separated by wider interspaces; the lowest and strongest spiral is on the subangular periphery; the uppermost spiral is the weakest of the three. A pair of spirals of medium strength on the base is separated from the first spiral above by a profound channel; several fine, obscure spirals may be seen lower on the base. The suture separating the body whorl from the penultimate whorl lies closely below the crest of the upper of the pair of basal spirals, previously mentioned, leaving the deep channel exposed at the base of the penultimate and smaller whorls. The spirals remain strong on the penultimate and antepenultimate whorls. The incrementals produce an obscurely punctate effect. The dimensions are: Height, 3 millimeters; diameter, 2.6 millimeters.

U. S. Geological Survey, Washington, D. C.

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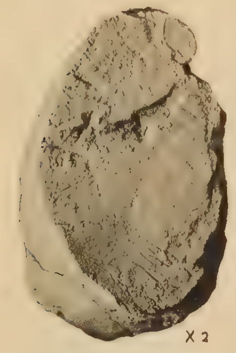
Contribution No. 81, Woods Hole Oceanographic Institution.

EXPLANATION OF PLATES



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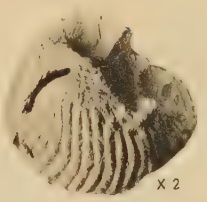

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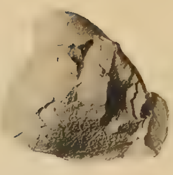

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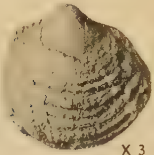

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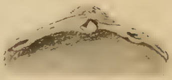

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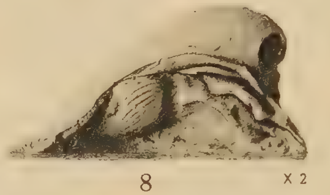

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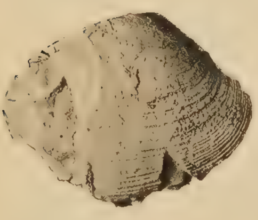

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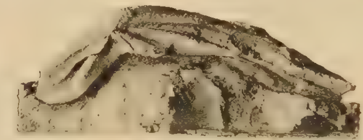

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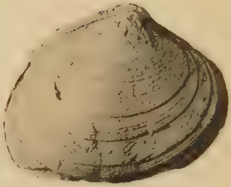

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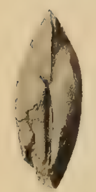

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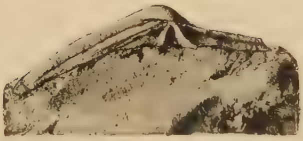

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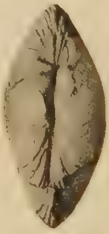

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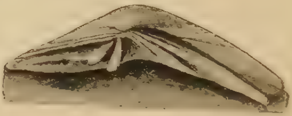

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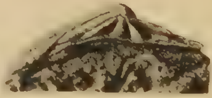

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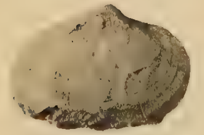

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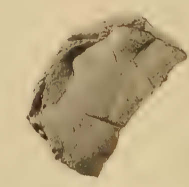

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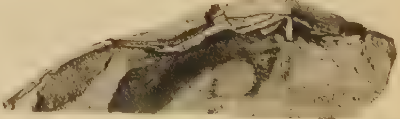

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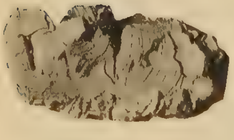

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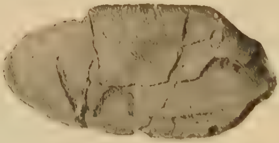

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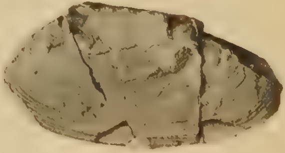


18

UPPER CRETACEOUS FOSSILS FROM BANQUEREAU

PLATE 2

UPPER CRETACEOUS FOSSILS FROM GEORGES BANK

Figures natural size except as indicated on plate.

Figure 1.—*Cardium (Trachycardium) longstreeti* Weller? Internal mold of right valve (M.C.Z. 15095).

Figures 2, 3.—*Cardium (Trachycardium) vaughani* Stephenson. (2) Squeeze of external mold (M.C.Z. 15097), closely associated in matrix with internal mold of *Crassatellites roodensis* (M.C.Z. 15090; Pl. 1, fig. 15); (3) internal mold of right valve (M.C.Z. 15098).

Figures 4, 5.—*Cardium (Trachycardium)* sp. (4) Squeeze of external mold of a large left valve (M.C.Z. 15100); (5) squeeze of external mold of a smaller right valve (M.C.Z. 15101).

Figures 6, 7.—*Cardium* (*Criocardium*) *atlanticanum* Stephenson. (6) Squeeze of external mold of holotype (M.C.Z. 15103); (7) internal mold of holotype.

Figure 8.—*Liopistha* sp. Squeeze of fragment of external mold (M.C.Z. 15088).

Figures 9, 10.—*Cyclina parva* Gardner(?). (9) Internal mold of right valve (M.C.Z. 15106); (10) squeeze of hinge made from the preceding mold, the hinge features of which were partly destroyed in making the squeeze.

Figures 11, 12.—*Tellina* sp. (11) Squeeze of incomplete external mold of left valve (M.C.Z. 15107); (12) internal mold of the same specimen.

Figure 13.—*Tellina* sp. Internal mold of a large right valve (M.C.Z. 15108).

Figure 14.—*Tellina* sp. Squeeze of external mold of a small right valve (M.C.Z. 15109).

Figure 15.—*Trigona* sp. Squeeze of incomplete small right valve (M.C.Z. 15086).

Figure 16.—*Crassatellites*(?) sp. Internal mold (M.C.Z. 15093).

Figure 17.—*Cymbophora* sp. Squeeze of external mold of left valve (M.C.Z. 15112).

Plate 3

UPPER CRETACEOUS FOSSILS FROM GEORGES BANK AND BANQUEREAU

Figures natural size except as indicated on plate.

Fossils from Georges Bank

Figures 1-3.—*Donax*(?) *atlantis* Stephenson, n.sp. (1) Squeeze of external mold of holotype, a left valve (M.C.Z. 15114); (2) internal mold of holotype; (3) squeeze of incomplete hinge of one of the paratypes, a right valve (M.C.Z. 15115).

Figure 4.—*Corbula* sp. *a*. Squeeze of external mold of right valve (M.C.Z. 15118).

Figure 5.—*Corbula* sp. *b*. Squeeze of external mold of a left valve (M.C.Z. 15119), closely associated in matrix with the bryozoan species *Plethopora americana* Bassler (M.C.Z. 8761). (*See* Pl. 1, fig. 18.)

Figure 6.—*Polinices*(?) sp. Squeeze of an incomplete external mold (M.C.Z. 27918).

Figure 7.—*Turritella* sp. A fragment of the body whorl (M.C.Z. 27920).

Figure 8.—*Turritella*(?) sp. Squeeze of the external mold of a poorly preserved shell (M.C.Z. 27921).

Figures 9, 10.—*Cerithium georgesensis* Stephenson, n.sp. (9) Squeeze of external mold of the holotype (M.C.Z. 27926); (10) diagrammatic enlargement of the largest well-preserved whorl of the holotype.

Fossils from Banquereau

Figure 11.—*Parasmelia*(?) sp. A very imperfect specimen (Y.P.M. 14801).

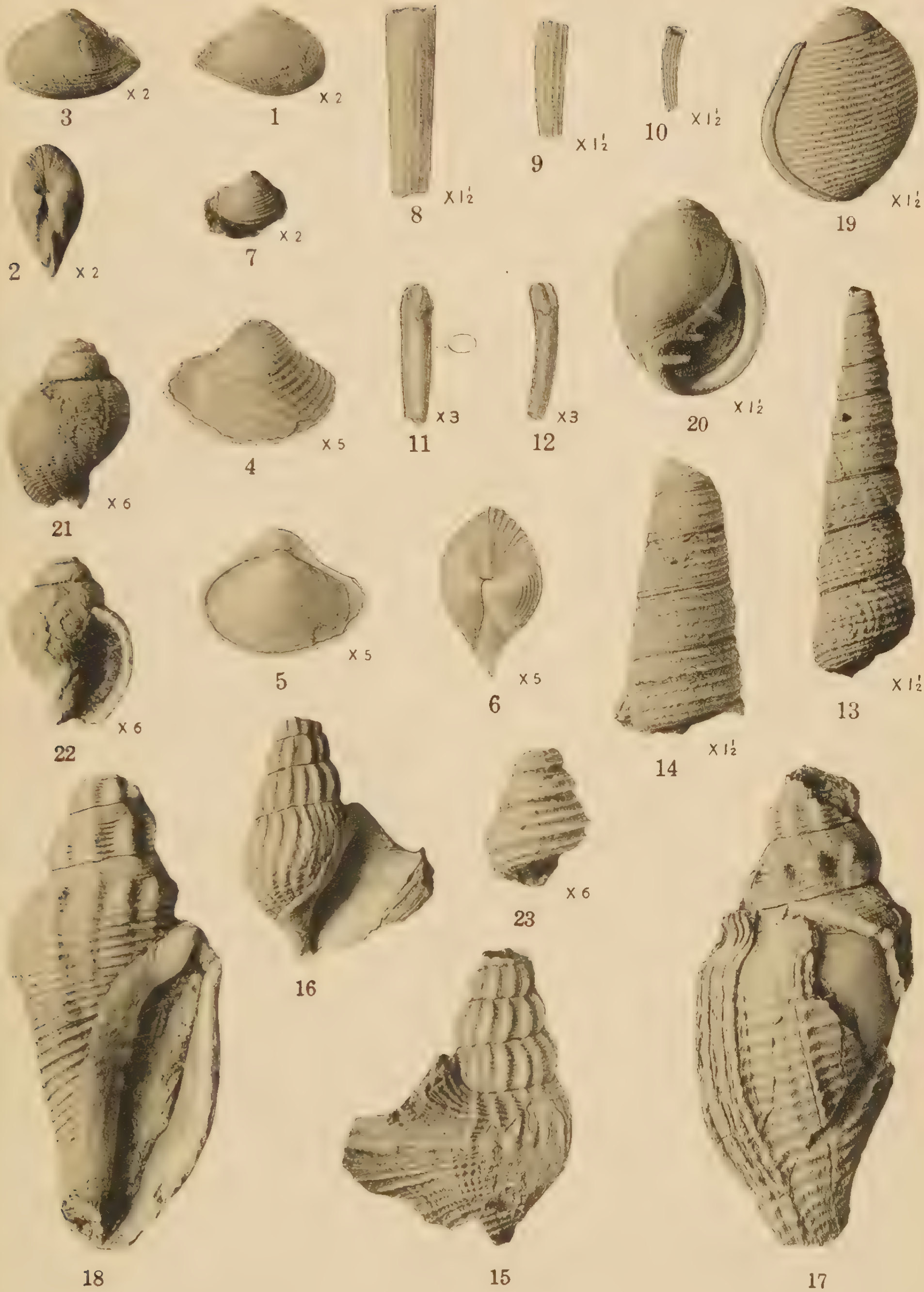
Figures 12-14.—*Acila banquereauensis* Stephenson, n.sp. (12) Right valve of the holotype (Y.P.M. 14804); (13) view of the posterior end and part of the ventral surface of the holotype; (14) one of the paratypes, a left valve (Y.P.M. 14805).

Figures 15, 16.—*Nuculana piscatoria* Stephenson, n.sp. (15) Right valve of the holotype (Y.P.M. 14807); (16) dorsal view of the holotype.

Figures 17, 18.—*Breviarca scotiensis* Stephenson, n.sp. (17) The holotype, a left valve (Y.P.M. 14809); (18) dorsal view of the holotype.

Figures 19, 20.—*Pteria*(?) *dalli* Stephenson, n.sp. (19) The holotype, an incomplete left valve (Y.P.M. 14811); (20) the hinge of the holotype, incomplete at both ends.

Figures 21, 22.—*Pecten (Camptonectes) microcancelli* Stephenson, n.sp. (21) The holotype, a right valve (Y.P.M. 14817); (22) part of surface of holotype, enlarged to show details of sculpture.



UPPER CRETACEOUS FOSSILS FROM BANQUEREAU

Plate 4

UPPER CRETACEOUS FOSSILS FROM BANQUEREAU

Figures natural size except as indicated on plate.

Figure 1.—*Exogyra* sp. (smooth). A young left valve (Y.P.M. 14813); the scar of attachment to a smooth object covers more than half of the outer surface.

Figure 2.—*Exogyra* sp. (costate). A young left valve (Y.P.M. 14815); considerably distorted by scar of attachment to a gastropod.

Figures 3, 4.—*Etea* sp. (3) An incomplete right valve (Y.P.M. 14820); (4) incomplete hinge of the same specimen.

Figures 5, 6.—*Lucina olsoni* Stephenson, n.sp. (5) Right valve of the holotype (Y.P.M. 14821); (6) brush drawing of hinge of one of the paratypes, a left valve (14822).

Figures 7, 8.—*Isocardia novensis* Stephenson, n.sp. (7) The holotype, a left valve (Y.P.M. 14824); (8) hinge of the holotype, partly broken.

Figures 9-12.—*Aphrodina marina* Stephenson, n.sp. (9) Right valve of the holotype (Y.P.M. 14826); (10) dorsal view of the holotype; (11) hinge of one of the paratypes, a left valve (Y.P.M. 14827); (12) hinge of right valve, a brush drawing made from 2 incomplete paratypes (Y.P.M. 14828).

Figure 13.—*Cyprimeria* sp. An incomplete left valve (Y.P.M. 14830).

Figures 14-16.—*Cyclorisma elongata* Stephenson, n.sp. (14) Right valve of the holotype (Y.P.M. 14832); (15) dorsal view of the holotype; (16) hinge of one of the paratypes, a left valve (14833).

Figures 17-19.—*Legumen intermedium* Stephenson, n.sp (17) Right valve of the holotype (Y.P.M. 14836); (18) left valve of the holotype; (19) one incomplete paratype, a left valve, figured for hinge (Y.P.M. 14837).

Figure 20.—*Leptosolen* sp. An incomplete left valve (Y.P.M. 14839).

Plate 5

UPPER CRETACEOUS FOSSILS FROM BANQUEREAU

Figures natural size except as indicated on plate.

Figures 1-3.—*Corbula latona* Stephenson, n.sp. (1) Right valve of holotype (Y.P.M. 14841); (2) dorsal view of holotype; (3) left valve of one of the paratypes (Y.P.M. 14842).

Figures 4-7.—*Corbula tethys* Stephenson, n.sp. (4) Brush drawing of right valve of holotype (Y.P.M. 14844); (5) brush drawing of left side of the holotype, showing overlap of right valve; (6) dorsal view of holotype, a brush drawing; (7) one of the paratypes, a nearly complete right valve (Y.P.M. 14845).

Figures 8-10.—*Dentalium* sp. (ribbed). Brush drawings of three fragments representing large, medium, and small parts of the tube (Y.P.M. 14847).

Figures 11-12.—*Dentalium* sp. (smooth). Brush drawings of an incomplete tube (Y.P.M. 14849).

Figure 13.—*Turritella macneili* Stephenson, n.sp. The holotype (Y.P.M. 14850).

Figure 14.—*Turritella thomsonina* Stephenson, n.sp. The holotype (Y.P.M. 14851).

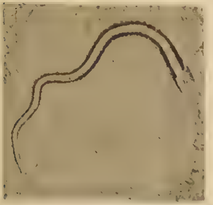
Figures 15, 16.—*Anchura pontana* Stephenson, n.sp. (15) The holotype (Y.P.M. 14853); (16) apertural view of the holotype.

Figures 17, 18.—*Volutoderma*(?) *venusta* Stephenson, n.sp. (17) The holotype (Y.P.M. 14855); (18) apertural view of the holotype.

Figures 19, 20.—*Avellana pelagana* Stephenson, n.sp. (19) The holotype (Y.P.M. 14857); (20) apertural view of the holotype.

Figures 21, 22.—A young unidentified gastropod (Y.P.M. 14858).

Figure 23.—A young unidentified gastropod (Y.P.M. 14860).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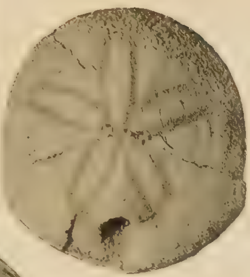
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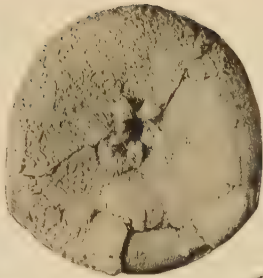
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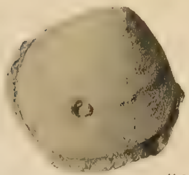
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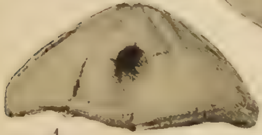
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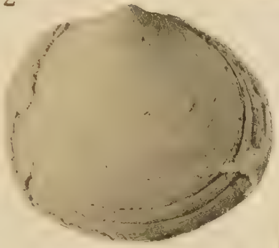
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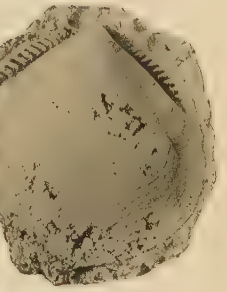
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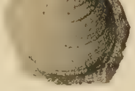
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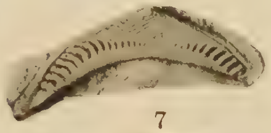
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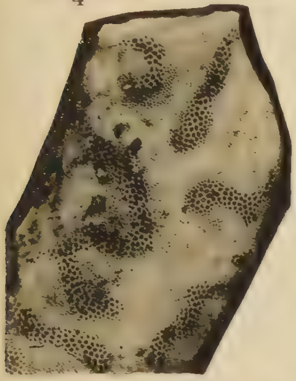
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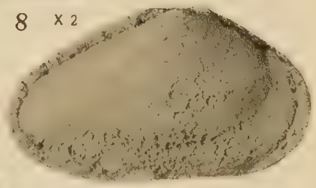
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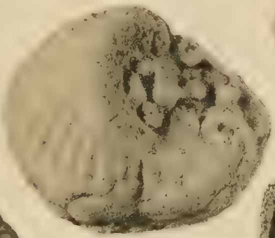
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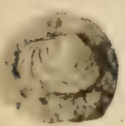
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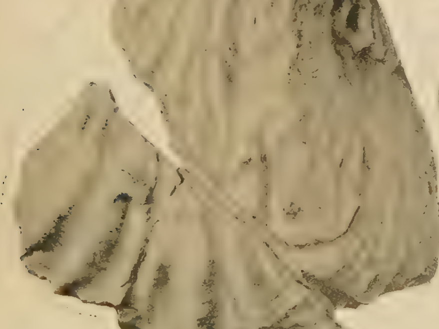
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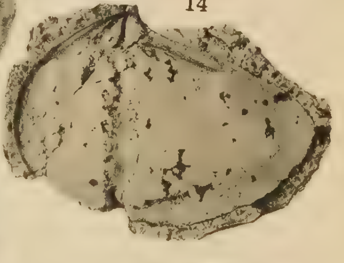
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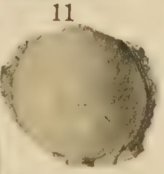
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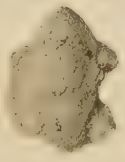
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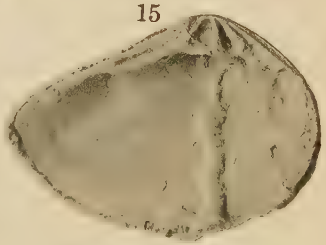
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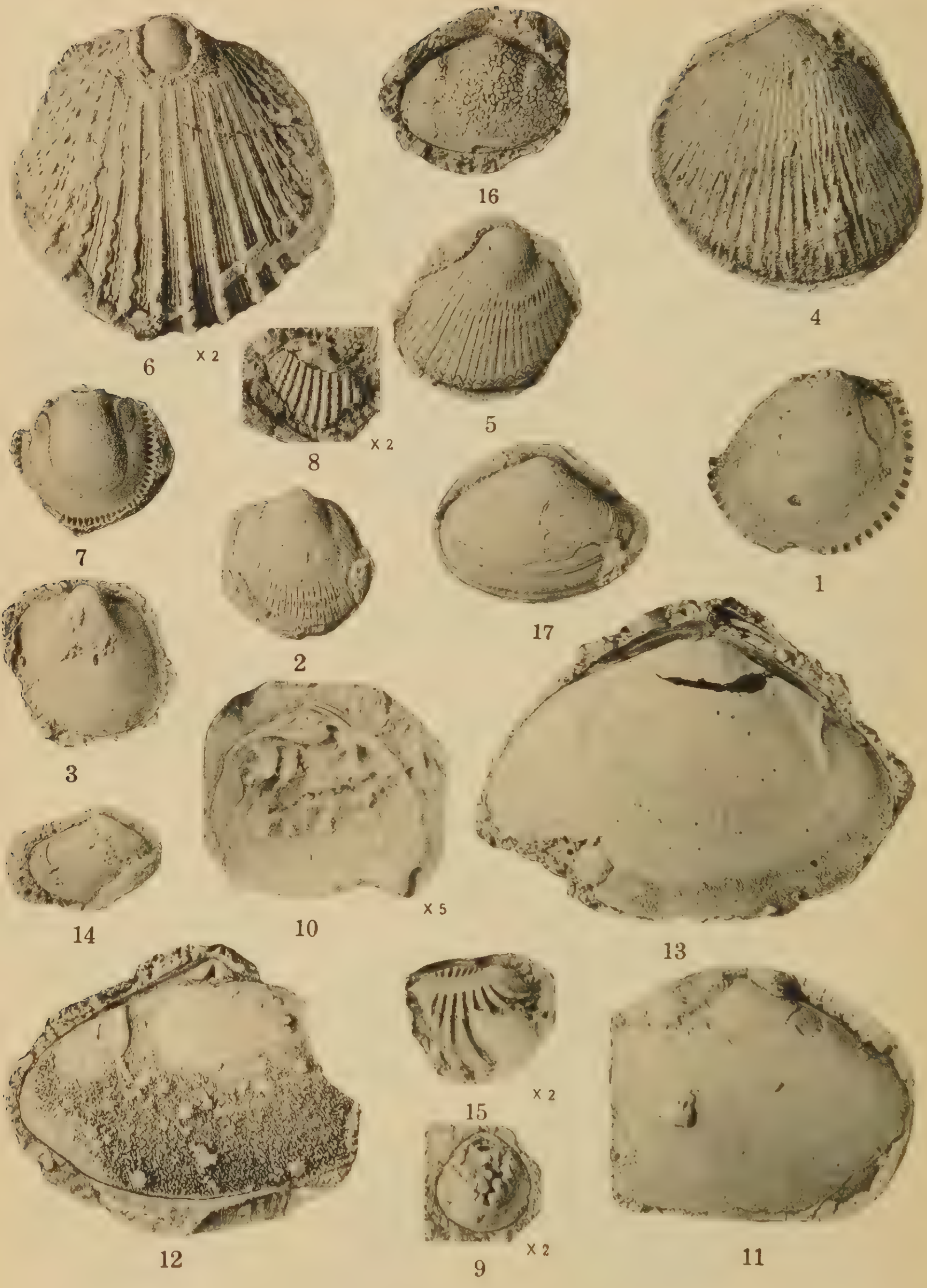
UPPER CRETACEOUS FOSSILS FROM GEORGES BANK



UPPER CRETACEOUS FOSSILS FROM GEORGES BANK

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GEOLOGY AND PALEONTOLOGY OF THE GEORGES BANK CANYONS

Part IV. CRETACEOUS AND LATE TERTIARY FORAMINIFERA

BY JOSEPH A. CUSHMAN

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INTRODUCTION

Of the various lots of foraminiferal material collected from the walls of the canyons on the south side of Georges Bank, one, the greensand from Canyon II, Tow 6, is very distinctively Cretaceous in age, the others, greensand and the silts, are of late Tertiary age.

The Cretaceous greensand contains a large fauna and is apparently to be correlated with faunas of known Upper Cretaceous, Navarro age, of the general Gulf Coastal Plain region. Unfortunately, the foraminiferal fauna of the Cretaceous of the Atlantic Coastal Plain is not yet well enough known, so that correlations with that area cannot be definitely made. Some of the species are identical with those of the Cretaceous, upper Selma chalk, of Tennessee, and most of them are found in clays of known Navarro age in the Texas area. The large number of species and their known vertical ranges show the undoubted Cretaceous age of this greensand and its correlation with the Navarro. Some of the more characteristic species are figured in Plate 1.

The late Tertiary greensand from Canyon III, Tow 9, has a peculiar fauna. It is definitely of more southern and warmer waters than is the fauna living today in the region of the Georges Bank. Most of the species are living, and their geographic ranges are West Indian, ranging northward to the coast of Florida or even to Cape Hatteras, but usually not north of this. There are some species that are of pelagic origin, and these are distributed far northward, even today, by the Gulf Stream.

Some of the species of this greensand also show relationships to those of the Pliocene of the western coast of the United States, and even to the Pliocene of Japan. This relationship is even more marked in the case of the silts of the canyon walls. It would seem to indicate that they were deposited in late Tertiary time, before the cooling of the waters by the accumulation of ice in the Pleistocene, and may possibly show that there was a definite connection across the Arctic, of the colder-water faunas of these otherwise disconnected regions.

Although both the late Tertiary greensand and the silts have a large proportion of species which are still living, there are, nevertheless, several species apparently not previously described. Of especial interest are the species of *Plectofrondicularia*, which resemble most closely the species of the California area but are not identical. The only species of this genus now living in the area, *P. advena* Cushman, does not occur in any of these samples.

With an almost entire absence of Pliocene foraminifera on the Atlantic Coast, especially faunas representing cool waters, it is difficult to determine with any certainty the exact age of this material. The great predominance of living species would indicate that both the greensand and the silts are of very late Tertiary age, and indications seem to point to late Pliocene or earliest Pleistocene as the most probable age. The greensand represents a warmer-water condition and is, therefore, probably older than the silts. It has also a slightly larger proportion of species not known to be living, although the indications are that some of those of the greensand will be found in the region south of Cape Hatteras, and, for those species of the silts not previously known, subsequent investigation will probably show specimens in the Georges Bank region.

A definite check of the present-day fauna has been possible through a study of the cores. The samples at the top of the cores represent the living fauna. Samples from below the top are, as a rule, more northern than the present fauna, and represent colder conditions than exist at present. A number of the species from these deeper samples are now known only from much farther north, in regions from Greenland, Fox Basin, and others.

New species from the greensand and silt samples have already been described in a short paper.[1] Figures of these new species, together with some of the more striking ones from the greensand and silt samples, are given on Plates 2 to 5.

Those species which are most useful in determining the age are noted, and references are given to the literature, where more complete information may be obtained as to other references or to distribution tables, particularly to Bulletin 104 of the United States National Museum on the Foraminifera of the Atlantic Ocean. These tables give the data of depth and temperature as well as the geographical positions of the stations from which the species have been obtained.

A short discussion of each of the samples follows, and the accompanying chart gives the distribution of some of the late Tertiary species in the greensand and silt samples, as well as in the cores. Many of the species, represented by too few or too poorly preserved specimens, are not used. Indications are, however, that they corroborate the age of the samples as already given.

Many species found in the cores do not occur at all in the samples from the canyon walls, and those, if completely studied, would show still further the distinction between the two groups of samples.

CRETACEOUS FORAMINIFERA

From Tow 6, Canyon II, the greensand sample contained about 85 species of foraminifera, all definitely Cretaceous, and correlating this particular sample with the Upper Cretaceous of Texas and the upper portion of the Selma chalk of Tennessee and Mississippi. Notes are given on those species which are well preserved, and something of their occurrence elsewhere in the Upper Cretaceous. Many other species are represented by insufficient specimens for exact determination, or they belong to species which are now in process of being studied in the preparation of the report on the American Cretaceous foraminifera. Enough species are given to show the undoubted relationship of this sample from Canyon II. It would be interesting for comparison, if one knew more about the Upper Cretaceous foraminifera of New Jersey. It is interesting, however, that some species, such as *Bolivinita selmensis* Cushman, occur in the material from the canyon wall, and are not known at the present time farther west than Tennessee.

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[1] J. A. Cushman: *Some new foraminifera from the late Tertiary of Georges Bank*, Contrib. Cushman Lab. Foram. Res., vol. 11 (1935) p. 77.

Some of the more striking species are illustrated by drawings of actual specimens from this sample of greensand. The number of these could be greatly increased, but it seems sufficient to figure only some of the more striking species of this fauna.

Verneuilina sp.(?)

(Plate 1, figures 1*a*, *b*)

This is a small species, very similar to that called *"Verneuilina polystropha"* from the Upper Cretaceous of Lizard Springs, Trinidad.[2] There are very few specimens, but they are all very similar.

Gaudryina sp.(?)

In the Georges Bank material, there is a large, rough *Gaudryina*, very similar to that figured from the Upper Cretaceous of Trinidad as *"G. laevigata* Franke, var. *pyramidata* Cushman."[3] A very similar form occurs also in the Upper Selma chalk of Mississippi.

Gaudryina cf. *laevigata* Franke

There is a single specimen in the greensand sample which may somewhat questionably be referred to this species, and is similar to ones found in the Upper Selma and Coon Creek of Tennessee.

Dorothia bulletta (Carsey)

(Plate 1, figures 2*a*, *b*)

1927. *Gaudryina bulletta* Carsey, Univ. Texas, Bull. 2612, p. 28, pl. IV, fig. 4.
1931. *Dorothia bulletta* Plummer, Univ. Texas, Bull. 3101, p. 132, pl. VIII, figs. 13-17.

This is a well-known species, most common in the Navarro formation of Texas, where it is especially abundant in the pit of the Corsicana Brick Company, near Corsicana, Texas. This, with other species, seems to fix very definitely the age of this greensand.

Robulus macrodiscus (Reuss)

In the greensand sample are specimens very similar to the ones figured under this name from the Upper Cretaceous of Trinidad.[4] There are a number of other species of *Robulus*, but for the most part they are represented by very few specimens.

Saracenaria sp.(?)

There are many specimens belonging to this genus, but they are mostly young stages, and it does not seem best to give them a distinct name. They probably belong to a species fairly common in the Upper Cretaceous of the Gulf Coastal Plain.

Vaginulina navarroana Cushman, n. sp.

(Plate 1, figure 3)

Test elongate, somewhat compressed, early portion somewhat coiled, later portion uncoiled, periphery somewhat rounded or subacute; chambers distinct, few, those of the uncoiled portion of rather uniform size and shape; sutures strongly oblique, very slightly limbate, slightly curved; wall covered with longitudinal costae, independent of the sutures; aperture at the dorsal angle, terminal, with a short neck. Length, 0.60–0.90 millimeter; breadth, 0.20–0.25 millimeter.

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[2] J. A. Cushman and P. W. Jarvis: *Upper Cretaceous Foraminifera from Trinidad*, U. S. Nat. Mus., Pr., vol. 80, art. 14 (1932) p. 15, pl. 4, figs. 3*a*, *b*.

[3] *Op. cit.*, p. 18, pl. 5, fig. 3.

[4] *Op. cit.*, pl. 7, fig. 3.

Holotype (Cushman Coll. No. 22159) from Cretaceous greensand, Canyon II, Tow 6, Georges Bank.

This species is a common and characteristic one of the Navarro formation of Texas, occurring in great numbers in the clays of the pit of the Corsicana Brick Company, near Corsicana, Texas, as well as elsewhere in the Navarro.

Vaginulina cf. *wadei* Kelley

(Plate 1, figure 4)

Although the figured specimen is broken, it evidently belongs to this species, which was described from the Upper Cretaceous, Coon Creek, of Tennessee, and has a rather wide distribution in the Upper Selma and its equivalents in the Gulf Coastal Plain region.

Vaginulina cretacea Plummer

(Plate 1, figure 5)

1927. *Vaginulina gracilis* Plummer, var. *cretacea* PLUMMER, Univ. Texas, Bull. 2644, p. 172, pl. II, fig. 8.

Mrs. Plummer described this species from the uppermost Navarro clays of Texas. It has been found to be widely distributed in the Navarro and its equivalents. It occurs in some numbers in the material under discussion, and a somewhat similar *V. silicula* (Plummer), which also occurs in the Navarro, was watched for, but no specimens were found.

This is another of those species which help to place definitely the age of this greensand.

Nodosaria sp.(?)

(Plate 1, figure 6)

This species with very pronounced costae is a common one of the Cretaceous, particularly of the Navarro, and helps to correlate this material.

Nodosaria affinis Reuss

This large species, which is rather common in much of the Gulf Coastal Plain Upper Cretaceous, occurs in rather typical form in the Georges Bank Cretaceous greensand.[5]

Dentalina cf. *adolphina* d'Orbigny

Numerous broken fragments, similar to that figured in the Tennessee report,[6] occur in the material. This is probably not the same as the species described by d'Orbigny, from the Miocene of the Vienna Basin, but the figures noted will serve to give good illustrations of this Cretaceous form.

Dentalina lorneiana d'Orbigny

This species is also figured in the Tennessee Cretaceous report.[7] It is an easily broken species, and the material shows only fragments.

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[5] J. A. Cushman: *A preliminary report on the Foraminifera of Tennessee*, Tenn. Div. Geol., Bull. 41 (1931) pl. 3, figs. 16-20.

[6] *Op. cit.*, pl. 3, figs. 10-12.

[7] *Op. cit.*, pl. 3, figs. 4-7.

Globulina lacrima Reuss

This Upper Cretaceous species is figured in the Tennessee report.[8]

Pseudopolymorphina digitata (d'Orbigny)

Some of the specimens from the Cretaceous greensand sample are very similar tc this species, which occurs in the Upper Cretaceous of Maastricht.[9]

Guttulina trigonula (Reuss)

There are numerous specimens in the Cretaceous greensand sample, both with and without fistulose projections, some of the former being rather complex. This species is figured in the Tennessee report.[10]

Nonionella cretacea Cushman

Rather typical specimens of this species occur in the Cretaceous greensand sample. It was described and figured in the Tennessee report,[11] from the Selma chalk of Tennessee. It also occurs in the upper Taylor and lower Navarro of Texas, as well as in the Velasco shale of Mexico.

Gümbelina striata (Ehrenberg)

(Plate 1, figures 11*a*, *b*)

Specimens somewhat similar to those figured in the Tennessee report[12] occur in the sample. They are somewhat similar to *Ventilabrella carseyae*, but none of the specimens show the *Ventilabrella* chambers.

Gümbelina globulosa (Ehrenberg)

(Plate 1, figures 8*a*, *b*)

This species is also figured in the Tennessee report.[13] It is very common in the Navarro of the Corsicana clay pit and elsewhere.

Gümbelina tessera (Ehrenberg)

(Plate 1, figures 9*a*, *b*)

This rather striking species occurs well developed in the Annona chalk of Texas.[14]

Gümbelitria cretacea Cushman

(Plate 1, figures 12*a*, *b*)

This is one of the interesting species of the Cretaceous greensand from the Georges Banks. It is particularly a Navarro species, but is widely distributed.

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[8] *Op. cit.*, pl. 6, figs. 9*a-c*.

[9] J. A. Cushman and Yoshiaki Ozawa: *Monograph of the foraminiferal family Polymorphinidae, recent and fossil*, U. S. Nat. Mus., Pr., vol. 77, art. 6 (1930) p. 108, pl. 28, figs. 3*a*, *b*.

[10] *Op. cit.*, pl. 6, figs. 3, 4.

[11] *Op. cit.*, p. 42, pl. 7, figs. 2*a-c*.

[12] *Op. cit.*, pl. 7, figs. 6, 7.

[13] *Op. cit.*, pl. 7, figs. 3-5.

[14] J. A. Cushman: *The Foraminifera of the Annona chalk*, Jour. Pal., vol. 6, no. 4 (1932) p. 338, pl. 51, figs. 4, 5.

Bolivinita selmensis Cushman

(Plate 1, figures 7*a*, *b*)

This species was described from the Upper Selma chalk.[15] The writer has not found this species west of Tennessee, and it is, therefore, interesting to find it occurring in rather typical form in this greensand material. It is one of the species which should serve to correlate the sample closely with the upper portion of the Selma chalk.

Pseudouvigerina plummerae Cushman

(Plate 1, figures 13*a*, *b*)

This species is also figured in the Tennessee report.[16] Its range is apparently from the Pecan Gap chalk upward into the Navarro of Texas, and it also occurs in the Selma chalk of Tennessee.

Bulimina quadrata Plummer

This species, which is so abundant in the Navarro of the Corsicana clay pit that the particular part of the Navarro is often called the *Bulimina*-zone, occurs in rather typical form in the greensand sample.[17]

Virgulina navarroana Cushman

This species is also abundant in the Corsicana clay pit in the Navarro of Texas.

Loxostomum plaitum (Carsey)

(Plate 1, figures 10*a*, *b*)

This is another of the species which serves to connect the greensand sample with the Navarro of Texas.

Gyroidina depressa (Alth)

Very typical specimens of this species, similar to those figured in the Tennessee report,[18] occur in the greensand sample.

Globigerina rugosa Plummer

There are very typical specimens of this species, described by Mrs. Plummer from the Navarro of Texas.[19]

Globotruncana arca (Cushman)

(Plate 1, figures 14*a-c*)

One of the typical high-spired forms is figured on Plate 1. This is very similar to the ones that occur in the Navarro of Texas, and resembles that figured in the Tennessee report,[20] except for the somewhat higher spire.

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[15] J. A. Cushman: *Post-Cretaceous occurrence of Gümbelina with a description of a new species,* Contrib. Cushman Lab. Foram. Res., vol. 9 (1933) p. 66, pl. 7, figs. 3, 4.

[16] *Op. cit.*, pl. 7, figs. 15, 16.

[17] J. A. Cushman: *A preliminary report on the Foraminifera of Tennessee,* Tenn. Div. Geol., Bull. 41 (1931) pl. 7, figs. 17, 18.

[18] *Op. cit.*, pl. 9, figs. 7, 8.

[19] H. J. Plummer: *Foraminifera of the Midway formation in Texas,* Univ. Texas Bull., no. 2644 (1926) p. 172, pl. 2, figs. 9*a-d*.

[20] J. A. Cushman: *A preliminary report on the Foraminifera of Tennessee,* Tenn. Div. Geol., Bull. 41 (1931) pl. 11, figs. 6*a-c*.

LATE TERTIARY FORAMINIFERA

GREENSAND

From Tow 9, Canyon III, a greensand was obtained, which, on washing, proved to contain an excellent foraminiferal fauna. The number of species is comparatively large, between fifty and sixty having been obtained, some of them represented by single specimens or incomplete ones. In cases where material is insufficient, specific determinations were not usually made, but there are many forms which may be specifically identified, and on these the age of this greensand is based. There are a number of new species and varieties in this material, which have their relationships with species usually developed much farther south than this particular region of the Georges Bank. Of the other species which may be specifically identified, the great majority are now living, and are to be found in warmer regions, particularly the Gulf of Mexico, and the southeastern coast of the United States, southward of Cape Hatteras. This would seem to indicate definitely that the waters in which these species lived and were deposited were much warmer than those of the present day at the point where they are found. Altogether, it seems rather definite that this fauna represents a condition which prevailed before the actual glacial period, as the waters in the region of the Georges Bank at that time were evidently decidedly warm compared with the present conditions. The fauna is very closely allied with the living one now found southward from Cape Hatteras, and no truly fossil species have been found in the fauna except those which are here described as new. From the associations of the other species of the fauna, it would seem rather certain that these new species will be found living in southern waters, when more work is done on that area.

Some of the characteristic species are illustrated in the accompanying plates, particularly those which are of interest from the point of view of the age and relationships of this greensand. Notes on some of the species follow:

Saracenaria sp.(?)

This form resembles very closely that figured in Bulletin 104 of the United States National Museum.[21] This particular form has been recorded from the Gulf of Mexico, and from the Atlantic coast as far north as South Carolina.

Robulus sp.(?)

(Plate 2, figure 3)

The particular specimen figured closely resembles that described in United States National Museum Bulletin 104, also from off the coast of South Carolina.[22]

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[21] J. A. Cushman: *The Foraminifera of the Atlantic Ocean*, U. S. Nat. Mus., Bull. 104, pt. 4 (1923) pl. 35, figs. 5-7.

[22] *Op. cit.*, pl. 21, fig. 7.

Robulus d'orbignyii (Bailey)

(Plate 2, figures 1*a*, *b*)

The figured specimen rather closely resembles that described in United States National Museum Bulletin 104, with a very distinct keel.[23] This species, described by Bailey from off the eastern coast of the United States, is known from the latitude of Cape Cod southward to Cape Hatteras, and specimens have since been found extending its range farther to the south.

Robulus sp.(?)

(Plate 2, figures 2*a*, *b*)

This is one of the large, distinctive species of the greensand not found in the silt samples, and is figured for future reference.

Marginulina cf. *schloenbachi* (Reuss) (?)

(Plate 2, figure 6)

This particular form has already been recorded from the Gulf of Mexico and along the Atlantic coast northward in deeper water. It is the form figured in Bulletin 104 of the United States National Museum,[24] and is not the species figured and described by Reuss.

Marginulina georgiana Cushman

(Plate 2, figures 4, 5)

Marginulina georgiana CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 77, pl. 12, figs. 2, 3.

This new species, which has recently been described, is a striking one, and rather common in this material. It has not been found in any of the silt samples, nor in the cores from this vicinity, but it is to be looked for in Recent material from Cape Hatteras southward to the Gulf of Mexico.

Dentalina cf. *adolphina* d'Orbigny

(Plate 2, figures 8, 9)

A number of fragmentary specimens, two of which are here figured, correspond well to the species referred to under this name from the general region of the Gulf of Mexico. It was not found in any of the other silt samples or cores.

Dentalina hirsuta (d'Orbigny), var. *aculeata* (d'Orbigny)

(Plate 2, figure 7)

Nodosaria aculeata D'ORBIGNY, Foram. Foss. Bass. Tert. Vienne (1846) p. 35, pl. 1, figs. 26, 27.

Nodosaria hirsuta d'Orbigny, var. *aculeata* CUSHMAN, U. S. Nat. Mus., Bull. 100, vol. 4 (1921) p. 214, pl. 38, figs. 7, 8; Bull. 104, pt. 4 (1923) p. 92, pl. 17, fig. 4.

This particular form has been recorded only in the western Atlantic, from stations in the Gulf of Mexico, where it is often relatively abundant. This is one of the species which shows strong evidence of the southern, warm relationship of this greensand.

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[23] *Op. cit.*, pl. 26, fig. 3.

[24] *Op. cit.*, pl. 5, fig. 10.

Nodosaria vertebralis (Batsch), var. *albatrossi* Cushman

(Plate 2, figures 13, 14)

Nodosaria vertebralis (Batsch), var. *albatrossi* Cushman, U. S. Nat. Mus., Bull. 104, pt. 4 (1923) p. 87, pl. 15, fig. 1.

This variety is common in Recent material in the Gulf of Mexico and off the southeastern coast of the United States, ranging northward to Cape Hatteras. It is another of the forms which show the relationships of this greensand to the fauna of more southern, warmer areas.

Marginulina bacheii Bailey

Marginulina bacheii Bailey, Smithsonian Contr., vol. 2 (1851) p. 10, pl., figs. 2-6. —Cushman, U. S. Nat. Mus., Bull. 104, pt. 4 (1923) p. 129, pl. 36, figs. 7-9.

Marginulina ensis Flint (not Reuss, 1846), U. S. Nat. Mus., Rept. 1897 (1899) p. 314, pl. 59, fig. 3.

A number of specimens with the initial end missing evidently belong to this large species, described by Bailey from off the eastern coast of America. It ranges from Cape Cod to Florida at the present time.

Dentalina cf. *filiformis* d'Orbigny

There are fragments only of the same form as that figured by Flint as "*Nodosaria filiformis* d'Orbigny."[25] The writer has had this particular form from Cape Hatteras southward to the Gulf of Mexico, and all of Flint's material came from the Gulf of Mexico, thus showing the decidedly southern range of this particular form.

Guttulina georgiana Cushman

(Plate 2, figures 12*a*, *b*)

Guttulina georgiana Cushman, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 78, pl. 12, figs. 4 *a*, *b*.

This new species is closely related to some of the other species of the genus which occur off the southeastern coast of the United States.

Pseudopolymorphina atlantica Cushman and Ozawa

Pseudopolymorphina atlantica Cushman and Ozawa, U. S. Nat. Mus., Pr., vol. 77, art. 6 (1930) p. 94, pl. 24, figs. 2 *a*, *b*.

Flint had a very similar form, but his plate 67, figure 3, contains more than one species, and *P. atlantica* is not the same as the broader *P. flintii* which was based on part of Flint's plate 67, figure 3. This species has also been recorded from the Atlantic coast of the United States.

Nonion pompilioides (Fichtel and Moll), var.

(Plate 2, figures 10*a*, *b*)

This compressed form occurs in a number of samples of silt as well as in this greensand, and needs further study before a definite name can be given to it.

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[25] J. M. Flint: *Recent Foraminifera,* U. S. Nat. Mus., Rept. 1897 (1899) p. 310, pl. 55, fig. 6. J. A. Cushman: *The Foraminifera of the Atlantic Ocean,* U. S. Nat. Mus., Bull. 104, pt. 4 (1923) pl. 12, fig. 2.

Nodogenerina georgiana Cushman

(Plate 2, figure 11)

Nodogenerina georgiana CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 80, pl. 12, fig. 16.

This new form somewhat resembles that described by Brady as "*Nodosaria hispida* (d'Orbigny), var. *sublineata* H. B. Brady." His form, while similar in ornamentation, has an elongate, slender aperture; this one has a short neck and lip.

Loxostomum georgianum Cushman

(Plate 2, figures 15, 16)

Loxostomum georgianum Cushman, n.sp., CUSHMAN, Contrib. Cushman Lab. Foram. Res., vol. 11 (1935) p. 82, pl. 12, figs. 14, 15.

This new species occurs in some numbers in the greensand, and is very similar in form and probably identical with material already collected from the West Indian region. There seem to be two distinct forms, both of which are figured—one, somewhat broader and more tapering, and having the apertural end more contracted; the other, more slender, and usually much more abundant.

Angulogerina angulosa (Williamson), var.

(Plate 2, figures 17*a*, *b*)

This is a much more slender form than the typical, and has more and finer costae. The typical form occurs in the silt samples from the canyon walls, but in the cores it is a still more slender form that is not found in the older silts.

Uvigerina auberiana d'Orbigny

(Plate 2, figures 18*a*, *b*)

The figured specimen shows a rather rough form, and apparently represents a young stage.[26] Other specimens from this same material, but not as well preserved, show the more typical, fusiform shape of the adult. It is a West Indian species, and not known in the Recent fauna from the region from which the greensand came.

Uvigerina flintii Cushman

(Plate 3, figures 1, 2)

Uvigerina tenuistriata FLINT (not *U. tenuistriata* Reuss), U. S. Nat. Mus., Rept. 1897 (1899) p. 320, pl. 68, fig. 1.

Uvigerina flintii CUSHMAN, U. S. Nat. Mus., Bull. 104, pt. 4 (1923) p. 165, pl. 42, fig. 13.

This is a typical, southern species, ranging from the coast of Georgia southward into the Gulf of Mexico and the Caribbean. It occurs in the greensand in considerable numbers, and has been compared with the types. It is another of those species which shows the relationships of this greensand fauna to the Recent material from much farther south.

Unicosiphonia crenulata Cushman

(Plate 3, figures 5, 6)

Unicosiphonia crenulata CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 81, pl. 12, figs. 9, 10.

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[26] J. A. Cushman: *Op. cit.*, p. 163.

A number of specimens of this species occur in the greensand material, and it is to be looked for as a living form in the general West Indian region.

Patellina corrugata Williamson

A single specimen of this species occurs in the greensand, but not in any of the silts from the canyon walls nor in any of the cores. It is a rare species in the Georges Bank area, as far as the records show, but has been recorded from wharf piles at Woods Hole.

Valvulineria georgiana Cushman

(Plate 3, figures 3*a-c*)

Valvulineria georgiana Cushman, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 82, pl. 12, figs. 17 *a-c*.

This new species has its relationships with those of the eastern Pacific and the warmer parts of the Atlantic.

Gyroidina soldanii d'Orbigny

There is only one specimen in this material. It resembles that of figure 3 on plate 8 in part 8 of Bulletin 104 of the United States National Museum, rather than any of the other figures given on that plate. It is recorded from this area as a living species.

Eponides umbonata (Reuss)

(Plate 3, figures 4*a-c*)

This species has a wide range, and is not significant as far as helping to determine the age of this material.[27]

Siphonina pulchra Cushman

(Plate 3, figures 7*a-c*)

This species was not found in any of the silt samples from the canyon walls nor in any of the cores. Its range, as far as known, in present seas is from the West Indies northward to the coast of Florida. It occurs in the Miocene of Cuba. It is one of the decidedly southern species from the greensand, one of those which indicates the much warmer conditions under which this greensand was deposited.[28]

Globigerina inflata d'Orbigny

This species, frequent in this sample, is common at the present time along the continental shelf, and is often very abundant in Recent collections from this same region.

Globigerina dubia Egger

Like the preceding species, this is common along the path of the Gulf Stream northward to Cape Cod.

Globigerinoides rubra (d'Orbigny)

(Plate 3, figures 8*a*, *b*)

This species is a typical one of the Gulf Stream region, reaching north to the general region of the Georges Bank at the present time. It is interesting, therefore, to find that the species does not occur in the silts from the canyon walls nor in the cores.

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[27] J. A. Cushman: *The Foraminifera of the Atlantic Ocean*, U. S. Nat. Mus., Bull. 104, pt. 8 (1931) p. 52.

[28] *Op. cit.*, p. 69.

Globigerinoides sacculifera (H. B. Brady)

This species was found only in Canyon III, but occurs there both in the silt and in the greensand samples. It occurs in a few of the cores, and then only rarely.

Globorotalia menardii (d'Orbigny)

As in the preceding species, this occurs both in the greensand and in the silt from Canyon III. It occurs in many of the core samples, especially of the Gulf Stream area.

Globorotalia hirsuta (d'Orbigny)

(Plate 3, figures 13*a-c*)

This occurs in both the silt and the greensand from Canyon III, but is rare elsewhere in the region, as far as samples show.

Pullenia sphaeroides d'Orbigny

(Plate 3, figures 11*a*, *b*)

This species has a considerable range in the western Atlantic, and, like the following, probably is not significant in determining the age of this material.

Pullenia quinqueloba (Reuss)

(Plate 3, figures 10*a*, *b*)

This, like the preceding, is a widely distributed species.

Sphaeroidina bulloides d'Orbigny

(Plate 4, figures 1*a*, *b*)

This species occurs in the greensand and in all the silt samples from the canyon walls. It occurs in some of the cores, but is not frequent, as they represent probably colder conditions, for the most part.

Ehrenbergina trigona (Goës)

(Plate 3, figures 9*a*, *b*)

The range of this species is from the Caribbean to Cape Hatteras. It is another of the forms which show the southern relationships of the greensand. It does not occur in the silt samples from the canyon walls nor in the cores.[29]

Anomalina carinata Parker and Jones, var. *crassa* Cushman

(Plate 5, figures 13*a-c*)

This variety was described as living in this same region, but has apparently not been previously recorded as fossil.

Cibicides concentrica (Cushman)

A single, immature specimen probably represents this species, which is found in strata from Miocene to Recent. In the western Atlantic, it is known from Florida to Cape Hatteras, but is not recorded farther north.[30]

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[29] J. A. Cushman: *Foraminifera of the genus Ehrenbergina and its species*, U. S. Nat. Mus., Pr., vol. 70, art. 16 (1927) p. 6.

[30] J. A. Cushman: *The Foraminifera of the Atlantic Ocean*, U. S. Nat. Mus., Bull. 104, Pt. 8 (1931) p. 120.

Cibicides lobatula (Walker and Jacob)

This species is common, and has a wide range along the Atlantic coast.

Cibicides pseudoungeriana (Cushman)

The records indicate that this species ranges from Lower Oligocene to oceans of the present time, and has a rather wide range along the Atlantic coast.[31]

Cibicides sp.(?)

(Plate 4, figures 2*a-c*)

The only specimen of this unusual species is here figured. The ventral side is very much convex, the dorsal flattened or slightly concave, and the periphery has a very distinct, broad keel, most evident from the ventral side. This form is not found in any of the silt samples or cores.

GREEN SILTS

General statement—As a whole, these greenish consolidated silts of a clayey texture are much alike. The contained foraminifera are much more like those of the living fauna at this particular locality than are those species of the later Tertiary greensand already noted. The fauna as a whole is a cold-water one in comparison with that of the greensand, and evidently, from the number of living species, is younger than that of the greensand. As noted in the introduction, both the late Tertiary greensands and the silts show resemblances in their contained fauna to the late Pliocene of the West Coast of America and to Japan and the North Pacific.

Although the three green silt samples studied are very similar in their fauna, each has some distinctive species. For this reason, it is possible that they represent slightly different horizons, but the differences are not great enough to give a clue to which may be younger or older than others.

In order to form a check on the age of these silts taken from the canyon walls, a series of core samples from the bottom of the canyons were taken. When studied, these two sets of samples showed striking differences. One of these is in the various species of the genus *Plectofrondicularia*. There are three species in the silts from the canyon walls, but none of these species occurs in any of the core samples, either from the top of the core or from below. The species of *Bulimina* and *Bolivina* have little in common as they appear in the cores and in the silts from the canyon walls, yet the entire group of species of these two genera are living today. The same is true with other groups. Each silt sample from the canyon walls is discussed separately so far as the striking species are concerned, and a number of these species are figured. A chart showing the comparison of the fauna of the silts with those of the greensand and the cores is given.

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[31] *Op. cit.*, p. 123.

In studying the cores, which are of varying lengths, care was taken to wash separately material from about each inch of the core. It was found frequently that the foraminifera of the top sample, representing the present day fauna at this locality, were different from that of the sample at the bottom of the core, although this represented material from only a few inches below the present day floor. The chart shows the differences in the faunas from the top and the bottom samples of each core.

Sample from Canyon III, Tow 9.—The foraminifera of this sample and that from the silt from Canyon II, Tow 6, are very similar, as will be seen from the chart. The fauna is similar to the living one but has many elements that are distinct, particularly the species of *Plectofrondicularia.* There are some species in common with the late Tertiary greensand from this same Tow 9, but they are mostly pelagic ones widely distributed by warm ocean currents.

This and the other silts are distinctive from the present ocean-bottom samples and especially from the colder fauna found in some of the lower samples in the cores where Arctic species, such as *Globigerina pachyderma,* predominate. The following species seem worthy of note:

Proteonina difflugiformis (H. B. Brady)

This is a temperate or cold water species now living in this same region.[32]

Haplophragmoides canariensis (d'Orbigny)

(Plate 4, figures 5*a*, *b*)

This is one of the species of this general region which apparently does not extend much farther southward but does have a more northern extension of range.[33]

Haplophragmoides trullissata (H. B. Brady)

(Plate 4, figures 4*a*, *b*)

Like the preceding, this is a species now living in this region but extending northward into colder waters.[34]

Karreriella novangliae (Cushman)

This is one of the very typical living species of the region, and resembles species from the late Pliocene of Japan and from the Pliocene of Kar Nicobar.[35]

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[32] J. A. Cushman: *The Foraminifera of the Atlantic Ocean*, U. S. Nat. Mus., Bull. 104, Pt. 1 (1918) p. 47.

[33] *Op. cit.*, pt. 2, p. 38.

[34] *Op. cit.*, p. 43.

[35] *Op. cit.*, pt. 3, p. 76, pl. 13, fig. 4.

Listerella nodulosa (Cushman)

(Plate 4, figures 6*a*, *b*)

This is a species described from this general area as "*Clavulina communis* d'Orbigny, var. *nodulosa* Cushman."[36] This figured specimen is not a fully developed adult. Its definitely known range is from the region of Cape Cod southward to Cape Hatteras. It has not occurred in the core samples, possibly because they were taken in too deep water.

Listerella nodulosa (Cushman), var. *glabrata* Cushman

(Plate 4, figure 7)

Listerella nodulosa (Cushman) var. *glabrata* Cushman, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 77, pl. 12, fig. 1.

This variety, described from this material, appears in considerable number with the larger, typical form of the species. It is smaller, and the material of the wall is decidedly different. It occurs in several of the silt samples but not in the greensand.

Valvulina conica (Parker and Jones)

This is a widely distributed species now living in the region.[37]

Robulus cf. *calcar* (Linné)

(Plate 4, figures 8*a*, *b*)

The range of this particular form is from this region southward.[38]

Marginulina bacheii (Bailey)

This is another of the species described from Recent material of this same region and found in the silts.[39]

Glandulina laevigata d'Orbigny, var. *occidentalis* Cushman

(Plate 4, figure 12)

This variety is common as a living form in this same region.[40]

Elphidium georgianum Cushman

(Plate 3, figures 12*a*, *b*)

Elphidium georgianum Cushman, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 79, pl. 12, figs. 5*a*, *b*.

This is a species which is a striking form in many of the cores, especially in the portions below the actual surface. It occurs only in the silts in this Tow 9.

Plectofrondicularia basi-spinata Cushman

(Plate 5, figures 2*a*, *b*)

Plectofrondicularia basi-spinata Cushman, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 79, pl. 12, figs. 11*a*, *b*.

This and the following species represent distinct elements of the faunas from the silt samples of the canyon walls that do not occur in the cores, either at the surface or below.

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[36] *Op cit.*, pt. 3, p. 85, pl. 18, figs. 1-3.

[37] *Op. cit.*, p. 62.

[38] *Op. cit.*, pt. 4, p. 115.

[39] *Op. cit.*, p. 129.

[40] *Op. cit.*, p. 64.

Plectofrondicularia angusti-costata Cushman

(Plate 5, figures 5*a*, *b*)

Plectofrondicularia angusti-costata CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 80, pl. 12, figs. 12*a*, *b*.

See note with the preceding species.

Nodogenerina antillea (Cushman)

(Plate 5, figure 4)

This species is rather common in the silt sample but is not found in the cores. It is more southern in its distribution than most of the other species, being recorded as ranging from Brazil to the Carolinas.[41]

Virgulina fusiformis Cushman

(Plate 5, figures 6, 7)

Originally described from the Miocene of Florida, this species has been found to be common, not only in the silt samples from the canyon walls but also in the samples from the cores. It is a small species and has apparently been overlooked in this region or else has been mistaken for the young of some of the larger species so abundant here but which do not occur in the silts from the canyon walls.

Uvigerina peregrina Cushman, var. *bradyana* Cushman

(Plate 5, figures 10*a*, *b*)

This is another of the forms which is common in the living fauna of this region, also found in both the silts and the cores.[42]

Eponides frigida Cushman, var *calida* Cushman and Cole

Although now common in this region, this variety was discovered from the Pleistocene of Wailes Bluff, Maryland. It represents a somewhat warmer water variety of the more northern *E. frigida*.

Anomalina coronata Parker and Jones, var. *crassa* Cushman

(Plate 5, figures 13*a*-*c*)

All that is known of this peculiar thick-walled variety is from this particular region. It is interesting, therefore, to find it in the silt sample as well as in the greensand of this same Tow 9.[43]

Sample from Canyon III, Tow 11.—For the most part, the species from this sample are like those of Tow 9, but the fauna is not so rich, and more of the species are like the present-day fauna from this region. The presence of *Plectofrondicularia georgiana*, a species not found in any of the cores or surface samples, shows that it has certain elements not in the living fauna of this region, and so would tend to place it in the same group as the other silts, probably late Pliocene or early Pleistocene.

The species are for the most part noted in the other silts, and are given in the table (p. 433).

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[41] *Op. cit.*, p. 91.

[42] *Op. cit.*, p. 168.

[43] *Op. cit.*, pt. 8, p. 105.

Nodosaria cf. *tosta* Schwager

(Plate 4, figure 17)

This very elongate, slender species with high, plate-like, longitudinal costae occurs, as far as known, only at this station. It is close to the form found in the Pliocene of Humboldt County, California.[44] Schwager's type specimen is from the Pliocene of Kar Nicobar, and agrees well with the material from Georges Bank and from California.

Sample from Canyon II, Tow 6.—For the most part, the green silt from Tow 6, Canyon II, is very similar in its foraminiferal fauna to that from Tow 9, Canyon III. There are a very few species not found in the other green silts. The occurrence of the more important species will be found in the table (p. 432-433).

Nearly all the species are known in a living condition in this general region, and are also found in the core samples. As in the other silts, the presence of *Plectofrondicularia* is noteworthy, as this does not occur in any of the core samples. Species figured or not found in the other silts are noted.

Quinqueloculina sp.(?)

(Plate 4, figures 9*a-c*)

This is related to the colder-water species of this region, and is very rare, this being its only occurrence in any of the silt samples.

Pyrgo depressa (d'Orbigny)

(Plate 4, figure 10)

This is a species of cool, deep water of this general region and northward.[45]

Dentalina sp.(?)

(Plate 4, figure 11)

The figured specimen has only two chambers, and no specimens with more were found. The fragment shows, however, that this is exactly identical with three- and four-chambered fragments of the same species from the Arctic, collected by Captain Robert Bartlett. It evidently represents a cold-water species.

Nodosaria cf. *pauperata* d'Orbigny

Specimens similar to those referred to this species, and figured in Bulletin 104 of the United States National Museum,[46] occurred in this sample. The species is known from this general region and in the Arctic.

Nodosaria mucronata (Neugeboren)

This species, known from this region northward into the Arctic, occurred at this station.[47]

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[44] J. A. Cushman, R. E. Stewart and K. C. Stewart: *Tertiary Foraminifera from Humboldt County, Calif.; a preliminary survey of the fauna,* San Diego Soc. Nat. Hist., Tr., vol. 6 (1930) pl. 3, fig. 1.

[45] J. A. Cushman: *The Foraminifera of the Atlantic Ocean,* U. S. Nat. Mus., Bull. 104, pt. 6 (1929) p. 71.

[46] *Op. cit.,* pt. 4, pl. 14, fig. 13.

[47] *Op. cit.,* p. 80.

Glandulina basispinata Cushman

(Plate 4, figures 13-15)

Glandulina basispinata CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 78, pl. 12, figs. 6-8.

This peculiar species occurs in this material and also in Canyon III, Tow 9. It is to be looked for in Recent material of this same region.

Sigmomorphina williamsoni (Terquem)

(Plate 4, figure 16)

This species seems not to be known previously from the western Atlantic. It was originally described from off the British Isles.[48]

Nonion labradoricum (Dawson)

This is one of the characteristically cold-water species of the genus, ranging mostly northward from Cape Cod.[49]

Elphidium incertum (Williamson)

This is a typical species of this general region at the present time and ranges northward.[50]

Plectofrondicularia georgiana Cushman

(Plate 5, figures 3*a*, *b*)

Plectofrondicularia georgiana CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11 (1935) p. 79, pl. 12, figs. 13 *a*, *b*.

This species is found in some of the other silt samples but not in any of those from the cores. It is noteworthy that the three species occurring in the silt samples from the canyon walls do not occur in the core samples. *P. advena* Cushman does occur in Recent material from this region, but was not found in any of the silts from the canyon walls.

Bulimina gracilis Cushman

(Plate 5, figures 8*a*, *b*)

This species, described originally from the Miocene of Florida, occurs in this silt sample but not in the others.

Buliminella elegantissima (d'Orbigny)

This is a widely distributed species, occurring in all three silt samples from the canyon walls but not in the greensand. It is interesting to note that it occurred in only one of the core samples, and in that it was in the top sample only. It indicates a slight difference in the fauna of the silts and that of the present.

Bolivina alata (Seguenza)

(Plate 5, figures 9*a*, *b*)

This species, already noted from one of the other silts, is a widely distributed one. The figured specimen is from this sample.

---

[48] J. A. Cushman and Yoshiaki Ozawa: *Monograph of the foraminiferal family Polymorphinidae, recent and fossil,* U. S. Nat. Mus., Pr., vol. 77, art. 6 (1930) p. 138.

[49] J. A. Cushman: *The Foraminifera of the Atlantic Ocean,* U. S. Nat. Mus., Bull 104, pt. 7 (1930) p. 11.

[50] *Op. cit.*, p. 18.

TABLE 1.—*Distribution of Foraminifera in greensands and green silts of the canyon walls and in the cores.*
(In the cores, sample 1 is at the top.)

Specimens	Canyon III			Canyon II	Canyon III										Canyon II			Canyon I									
	Tow				Core																						
	9	9	11	6	10	11	7	7	8	8	9	9	16	16	5	5	5	3	3	2	2	2	1	1	1	4	4
	Green-sand	Silt	Silt	Silt	Sample																						
					3	1	6	1	4	1	4	1	2	1	1	3	5	1	4	1	3	5	1′	2	3	1	4
Saracenaria sp. (?)	X																										
Robulus sp. (?)	X										X																
Robulus d'orbignyi	X																										
Robulus sp. (?)	X																										
Marginulina cf. *schloenbachi*	X																										
Marginulina georgiana	X																										
Marginulina bacheii	X	X										X															
Dentalina cf. *adolphina*	X																										
Dentalina hirsuta, v. *aculeata*	X																										
Dentalina cf. *filiformis*	X																										
Nodosaria vertebralis, v. *albatrossi*	X																										
Guttulina georgiana	X																										
Pseudopolymorphina atlantica	X																										
Nonion pompilioides, var.	X											X															
Nodogenerina georgiana	X																										
Loxostomum georgianum	X																										
Angulogerina angulosa, var.	X					X					X																
Uvigerina auberiana	X																										
Uvigerina flintii	X																										
Unicosiphonia crenulata	X																										
Patellina corrugata	X									X		X															
Valvulineria georgiana	X																										
Gyroidina soldanii	X																										
Eponides umbonata	X								X								X										
Siphonina pulchra	X																										
Globigerina inflata	X					X	X		X		X			X	X	X	X									X	
Globigerina dubia	X																										
Globigerinoides rubra	X										X																
Globigerinoides sacculifera	X	X					X			X	X	X			X			X									
Globorotalia menardii	X	X			X	X	X		X		X	X			X		X	X	X	X			X		X	X	
Globorotalia hirsuta	X																										
Pullenia sphaeroides	X																										
Pullenia quinqueloba	X														X									X			
Sphaeroidina bulloides	X	X	X	X							X						X										
Ehrenbergina trigona	X																										
Anomalina carinata, v. *crassa*	X	X	X																	X							

Cibicides concentrica	X																										
Cibicides lobatula	X					X	X			X	X	X			X			X		X			X				
Cibicides pseudoungeriana	X				X		X		X	X	X	X			X		X	X									
Cibicides sp. (?)	X																										
Proteonina difflugiformis		X			X	X			X		X	X							X				X				
Haplophragmoides canariensis		X											X		X			X					X				
Haplophragmoides trullissata		X																									
Karreriella novangliae		X					X								X				X	X			X				
Listerella nodulosa		X			X				X																		
Listerella nodulosa, v. *glabrata*		X																									
Valvulina conica		X													X								X				
Robulus cf. *calcar*		X																									
Glandulina laevigata, v. *occidentalis*		X					X			X	X	X			X			X					X				
Glandulina basi-spinata		X																									
Elphidium georgianum		X			X			X	X			X			X				X				X	X	X		
Plectofrondicularia basi-spinata		X																									
Plectofrondicularia angusti-costata		X																									
Nodogenerina antillea		X																									
Virgulina fusiformis		X		X		X	X		X	X	X	X					X	X	X		X	X	X	X	X	X	
Uvigerina peregrina, v. *bradyana*		X				X					X	X					X						X	X		X	
Nodosaria cf. *tosta*			X																								
Quinqueloculina sp. (?)				X																							
Pyrgo depressa				X																							
Dentalina sp. (?)				X																							
Nodosaria cf. *pauperata*				X																							
Nodosaria mucronata				X																							
Sigmomorphina williamsoni				X						X																	
Nonion labradoricum				X	X	X	X	X	X	X	X	X			X		X	X	X	X	X	X	X	X			
Elphidium incertum				X																							
Plectofrondicularia georgiana		X	X	X																							
Bulimina cf. *gracilis*				X																							
Buliminella elegantissima		X	X	X																					X		
Bolivina alata				X		X																					
Eponides frigida, v. *calida*				X						X							X										
Globigerinoides conglobata	X		X	X		X	X										X	X	X	X							
Orbulina universa				X	X	X	X			X	X				X			X	X				X				
Cassidulina crassa				X	X	X			X	X	X	X					X			X	X	X		X	X	X	X
Cassidulina laevigata				X		X		X				X					X				X	X		X	X	X	
Bulimina exilis					X	X			X	X	X	X	X		X			X	X	X			X	X			
Robulus variabilis									X	X	X				X		X										
Bolivina aenariensis					X	X			X		X	X								X						X	
Virgulina compressa					X	X				X		X															
Bulimina marginata					X		X		X	X	X	X	X		X				X	X			X		X	X	
Vaginulina spinigera					X						X																
Globigerina pachyderma											X		X			X	X	X			X	X	X	X	X	X	X
Angulogerina angulosa					X				X	X	X	X	X		X		X	X	X	X			X	X	X	X	
Cassidulinoides parkeriana					X				X			X							X							X	

Eponides frigida (Cushman) var. *calida* Cushman and Cole

This variety occurs in this general region at the present time and also in silts both from the canyon walls and from the cores. The types are from the Pleistocene of Wailes Bluff, Maryland.

Globigerinoides conglobata (H. B. Brady)

This species was found in three of the four silt samples and in a few of the core samples. It occurs in this region now where the Gulf Stream influence at the surface carries these pelagic forms northward.

Orbulina universa d'Orbigny

This is the only sample from the canyon walls in which this species was found, though it normally occurs with the preceding and other related species that are present in the silt. It occurs in many of the core samples.

Cassidulina crassa d'Orbigny

(Plate 5, figures 12*a*, *b*)

This species is found in the silt samples from Canyon II, Tow 6, and Canyon III, Tow 9, as well as in the cores. As a living species, it is known from this general region and is widely distributed.[51]

Cassidulina laevigata d'Orbigny var.

(Plate 5, figures 11*a*, *b*)

This species occurs in the two silt samples already noted and in many of the cores.[52] The specimen figured is an abnormal one of this species, which occurs in all gradations from the typical form with an entire margin, to specimens with a decidedly lobular periphery.

DISTRIBUTION

In order to make more graphic for the reader, the distribution of the foraminifera in the late Tertiary greensand and silts from the canyon walls, and the cores, the table (p. 432-433) is presented. It will also serve to show the very considerable difference in faunas of the samples from greensand, Canyon III, Tow 9, and the three samples of silt from the canyon walls. It also shows the wide distribution of the pelagic species such as *Globigerina, Globigerinoides, Globorotalia,* in both the samples from the canyon walls and those from the cores. In order to make more definite the distinction between the present-day fauna of this region and the fossil ones of the canyon walls, the last nine species on the table show rather common and typical present-day species. It will be noted that none of these species occurs in the silt nor in the samples from the canyon walls. Sample 1 refers to the top of the core and the other numbers to varying parts of the same core. Number 1, therefore, in each core represents the actual fauna living at this point at the present time.

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[51] J. A. Cushman: *The Foraminifera of the Atlantic Ocean,* U. S. Nat. Mus., Bull. 104, pt. 3 (1922) p. 124.

[52] *Op. cit.*, p. 122.

Sharon, Mass.

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Read before the Geological Society, December 27, 1934. (Presented by Stetson, as part of the general problem, *see* p. 339.)
Contribution No. 82, Woods Hole Oceanographic Institution.

Plate 1

SPECIMENS FROM CRETACEOUS GREENSAND OF CANYON II, TOW 6

Figures 1*a*, *b*.—*Verneuilina* sp. (?) ×100. *a*, front view; *b*, apertural view.

Figures 2*a*, *b*.—*Dorothia bulletta* (Carsey). ×33. *a*, front view; *b*, apertural view.

Figure 3. —*Vaginulina navarroana* Cushman, n. sp. ×60.

Figure 4. —*Vaginulina* cf. *wadei* Kelley. ×33.

Figure 5. —*Vaginulina cretacea* Plummer. ×22.

Figure 6. —*Nodosaria* sp.(?). ×45.

Figures 7*a*, *b*.—*Bolivinita selmensis* Cushman. ×133. *a*, front view; *b*, apertural view.

Figure 8*a*, *b*.—*Gümbelina globulosa* (Ehrenberg). ×60. *a*, front view; *b*, apertural view.

Figures 9*a*, *b*.—*Gümbelina tessera* (Ehrenberg). ×80. *a*, front view; *b*, apertural view.

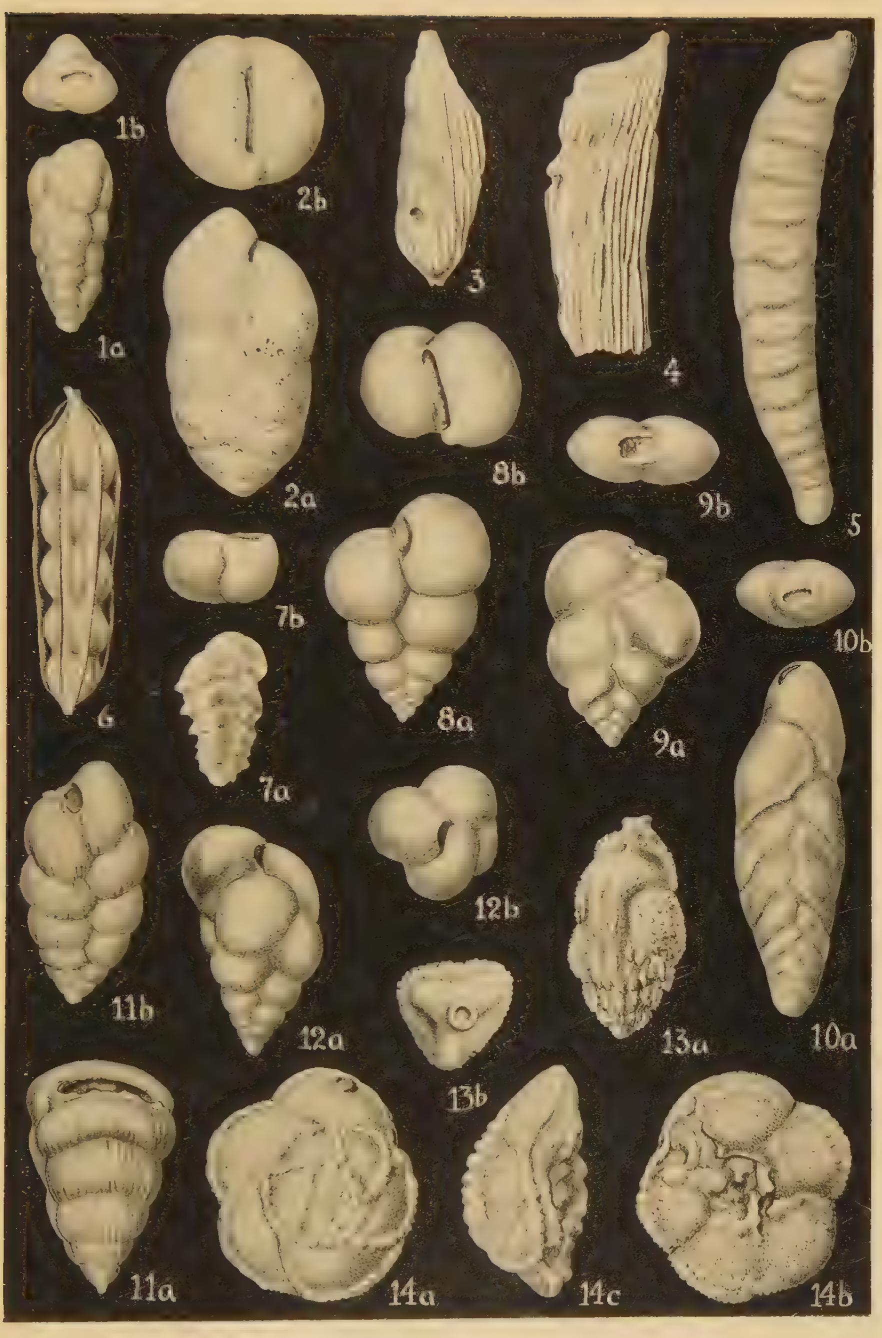
Figures 10*a*, *b*.—*Loxostomum plaitum* (Carsey). ×80. *a*, front view; *b*, apertura view.

Figures 11*a*, *b*.—*Gümbelina striata* (Ehrenberg). ×60. *a*, side view; *b*, front view.

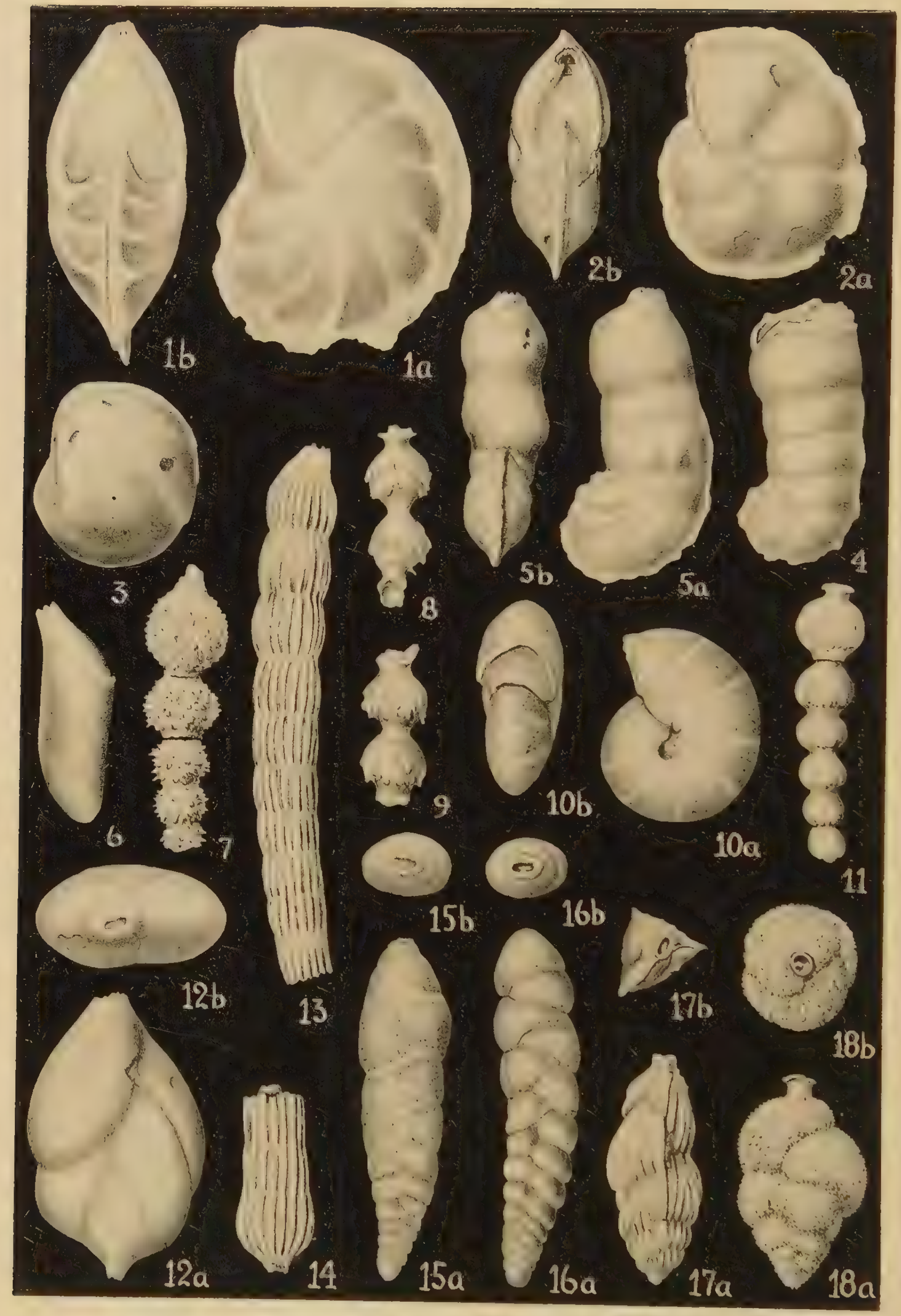
Figures 12*a*, *b*.—*Gümbelitria cretacea* Cushman. ×133. *a*, front view; *b*, apertural view.

Figures 13*a*, *b*.—*Pseudouvigerina plummerae* Cushman. ×110. *a*, front view; *b*, apertural view.

Figures 14*a*–*c*.—*Globotruncana arca* (Cushman). ×60. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.



SPECIMENS FROM CRETACEOUS GREENSAND OF CANYON II, TOW 6



SPECIMENS FROM THE GREENSAND OF CANYON III, TOW 9

PLATE 2

SPECIMENS FROM THE LATE TERTIARY GREENSAND OF CANYON III, TOW 9

Figures 1*a*, *b*.—*Robulus d'orbignyii* (Bailey). ×20. *a*, side view; *b*, peripheral view.

Figures 2*a*, *b*.—*Robulus* sp.(?). ×20. *a*, side view; *b*, peripheral view.

Figure 3. —*Robulus* sp.(?) ×33.

Figures 4, 5. —*Marginulina georgiana* Cushman. ×22. Fig. 4, Paratype. 5a, b, Holotype. *a*, side view; *b*, peripheral view.

Figure 6. —*Marginulina schloenbachi* (Reuss) (?). ×33.

Figure 7. —*Dentalina hirsuta* d'Orbigny, var. *aculeata* d'Orbigny. ×33.

Figures 8, 9. —*Dentalina* cf. *adolphina* d'Orbigny. ×33.

Figures 10*a*, *b*.—*Nonion pompilioides* (Fichtel and Moll), var. ×60.

Figure 11. —*Nodogenerina georgiana* Cushman. ×33.

Figures 12*a*, *b*.—*Guttulina georgiana* Cushman. ×27. *a*, front view; *b*, apertural view.

Figures 13, 14.—*Nodosaria vertebralis* (Batsch), var. *albatrossi* Cushman. ×20. 13, apertural portion; 14, initial portion.

Figures 15, 16.—*Loxostomum georgianum* Cushman. ×80. Fig. 15, Holotype; Fig. 16, Paratype. *aa*, front views; *bb*, apertural views.

Figures 17*a*, *b*.—*Angulogerina angulosa* (Williamson), var. ×80. *a*, front view; *b*, apertural view.

Figures 18*a*, *b*.—*Uvigerina auberiana* d'Orbigny. ×60. *a*, front view; *b*, apertural view.

Plate 3

SPECIMENS FROM THE LATE TERTIARY GREENSAND (FIGURE 12 FROM GREEN SILT) OF CANYON III, TOW 9

Figures 1, 2. —*Uvigerina flintii* Cushman. ×33. *aa*, front views; *bb*, apertura views.

Figures 3*a–c*. —*Valvulineria georgiana* Cushman. ×33. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.

Figures 4*a–c*. —*Eponides umbonata* (Reuss). ×80. *a*, dorsal; *b*, ventral; *c*, peripheral view.

Figures 5, 6. —*Unicosiphonia crenulata* Cushman. ×33. 5*a*,*b*, Paratype; *a*, side view; *b*, apertural view. Figure 6, Holotype.

Figures 7*a–c*. —*Siphonina pulchra* Cushman. ×60. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.

Figures 8*a*, *b*.—*Globigerinoides rubra* (d'Orbigny). ×60. *a*, dorsal view; *b*, ventra view.

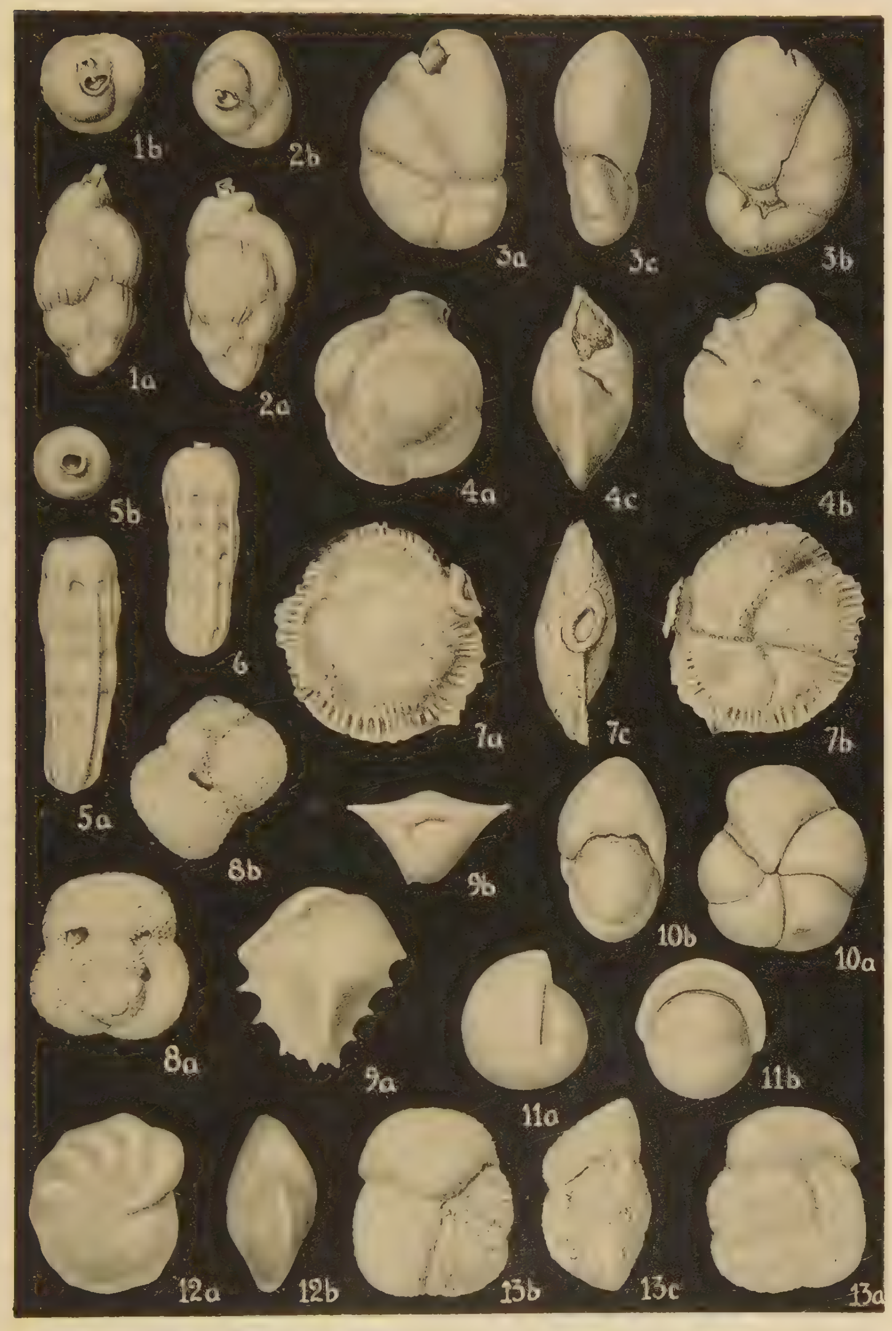
Figures 9*a*, *b*.—*Ehrenbergina trigona* (Goës). ×50. *a*, front view; *b*, apertural view.

Figures 10*a*, *b*.—*Pullenia quinqueloba* (Reuss). ×60. *a*, side view; *b*, apertural view.

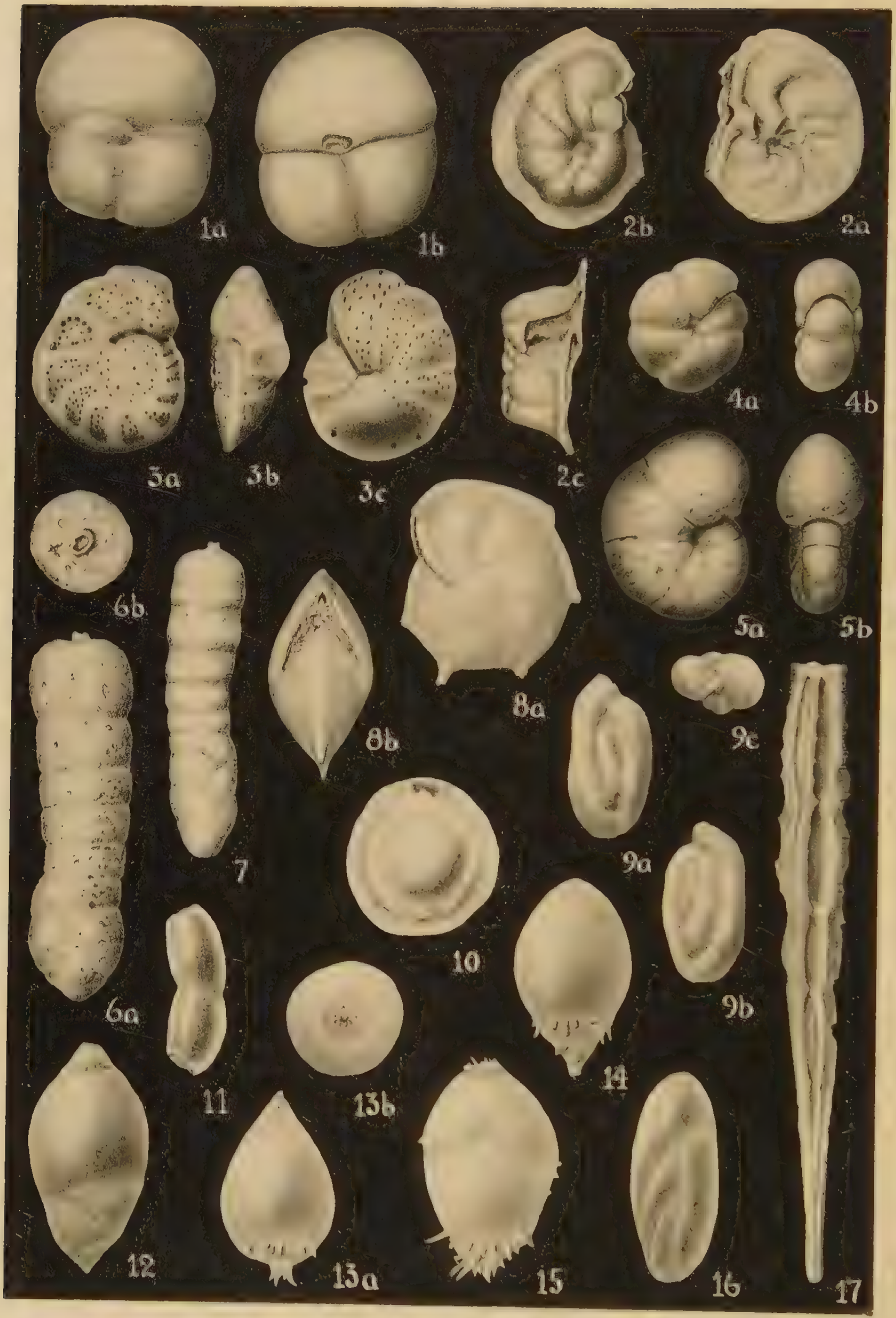
Figures 11*a*, *b*.—*Pullenia sphaeroides* d'Orbigny. ×80. *a*, side view; *b*, apertural view.

Figures 12*a*, *b*.—*Elphidium georgianum* Cushman. ×33. *a*, side view; *b*, apertural view. From Green clay of Canyon III, Tow 9.

Figures 13*a–c*. —*Globorotalia hirsuta* (d'Orbigny). ×50. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.



SPECIMENS FROM THE GREENSAND AND THE GREEN SILT OF CANYON III, TOW 9



SPECIMENS FROM LATE TERTIARY GREENSAND AND SILTS
OF CANYONS II AND III

PLATE 4

SPECIMENS FROM LATE TERTIARY GREENSAND AND SILTS OF CANYONS II AND III

Figures 1*a*, *b*.—*Sphaeroidina bulloides* d'Orbigny. ×45. *a*, dorsal view; *b*, ventral view.

Figures 2*a–c*.—*Cibicides* sp.(?). ×45. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.

Figures 3*a–c*.—*Cibicides pseudoungeriana* (Cushman). ×60. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.

Figures 4*a*, *b*.—*Haplophragmoides trullissata* (H. B. Brady). ×80. *a*, side view; *b*, peripheral view.

Figures 5*a*, *b*.—*Haplophragmoides canariensis* (d'Orbigny). ×45. *a*, side view; *b*, peripheral view.

Figures 6*a*, *b*.—*Listerella nodulosa* (Cushman). ×33. *a*, front view; *b*, apertural view.

Figure 7. —*Listerella nodulosa* (Cushman), var. *glabrata* Cushman. ×45.

Figures 8*a*, *b*.—*Robulus* cf. *calcar* (Linné). ×27. *a*, side view; *b*, peripheral view

Figures 9*a–c*.—*Quinqueloculina* sp.(?). ×60. *a*, *b*, opposite sides; *c*, apertural view.

Figure 10. —*Pyrgo depressa* (d'Orbigny). ×33.

Figure 11. —*Dentalina* sp.(?). ×60.

Figure 12. —*Glandulina laevigata* d'Orbigny, var. *occidentalis* Cushman. ×60.

Figures 13–15.—*Glandulina basispinata* Cushman. ×33. 13*a*, front view; *b*, apertural view.

Figure 16. —*Sigmomorphina williamsoni* (Terquem). ×60.

Figure 17. —*Nodosaria* cf. *tosta* Schwager. ×27.

PLATE 5

SPECIMENS FROM THE LATE TERTIARY GREEN SILTS

Figures 1*a–c*.—*Nonionella auris* (d'Orbigny). ×33. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.

Figures 2*a*, *b*.—*Plectofrondicularia basi-spinata* Cushman. ×27. *a*, front view; *b*, apertural view.

Figures 3*a*, *b*.—*Plectofrondicularia georgiana* Cushman. ×27. *a*, front view; *b*, apertural view.

Figure 4. —*Nodogenerina antillea* (Cushman). ×33.

Figures 5*a*, *b*.—*Plectofrondicularia angusti-costata* Cushman. ×33. *a*, front view; *b*, apertural view.

Figures 6, 7. —*Virgulina fusiformis* Cushman. ×80.

Figures 8*a*, *b*.—*Bulimina gracilis* Cushman. ×60. *a*, front view; *b*, apertural view.

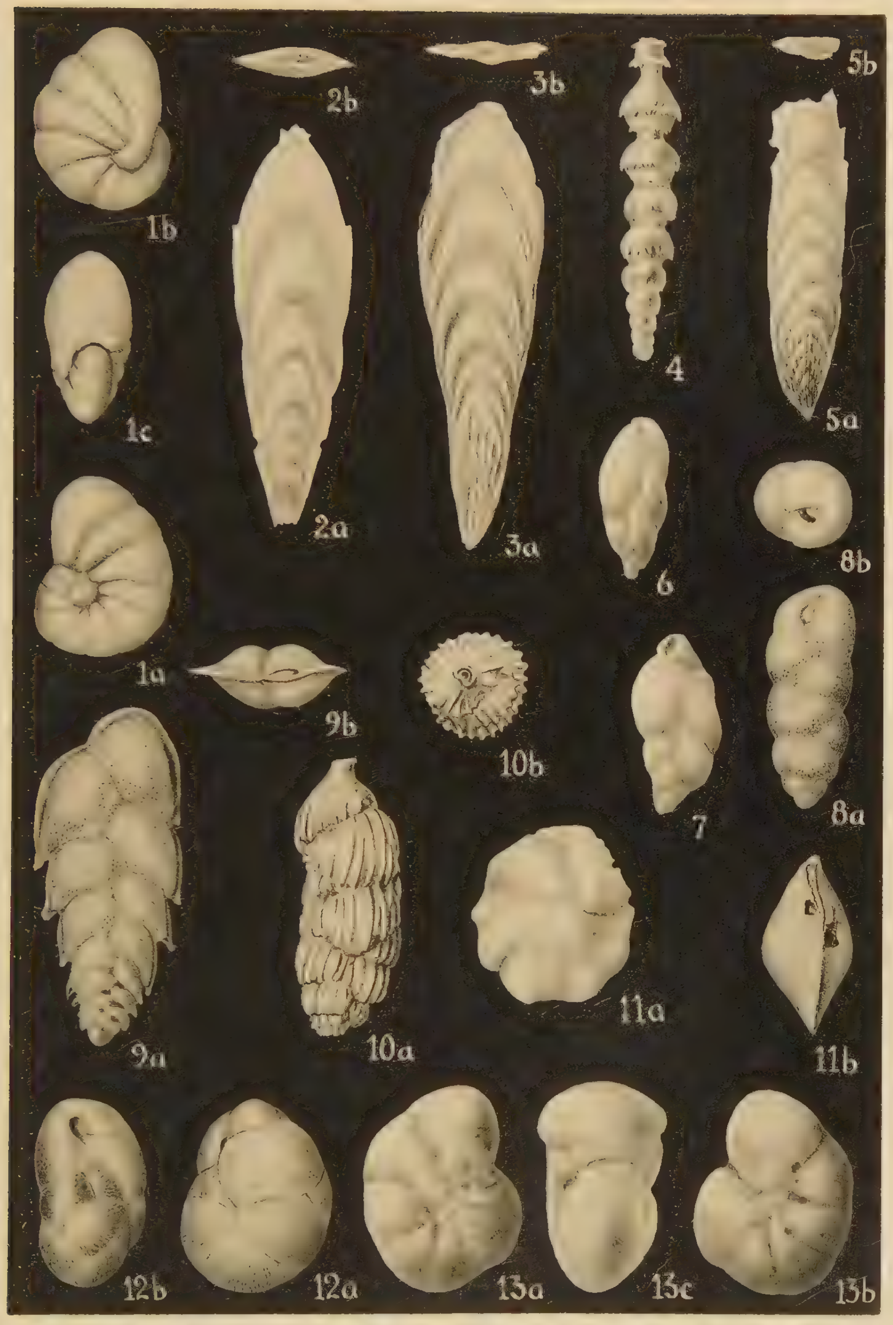
Figures 9*a*, *b*.—*Bolivina alata* (Seguenza). ×45. *a*, front view; *b*, apertural view.

Figures 10*a*, *b*.—*Uvigerina peregrina* Cushman, var. *bradyana* Cushman. ×45. *a*, front view; *b*, apertural view.

Figures 11*a*, *b*.—*Cassidulina laevigata* d'Orbigny, var. ×45. *a*, side view; *b*, peripheral view.

Figures 12*a*, *b*.—*Cassidulina crassa* d'Orbigny. ×60. *a*, side view; *b*, peripheral view.

Figures 13*a-c*.—*Anomalina coronata* Parker and Jones, var. *crassa* Cushman. ×33. *a*, dorsal view; *b*, ventral view; *c*, peripheral view.



SPECIMENS FROM LATE TERTIARY GREEN SILTS

Contribution No. 83

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PIGMENTS OF THE RETINA

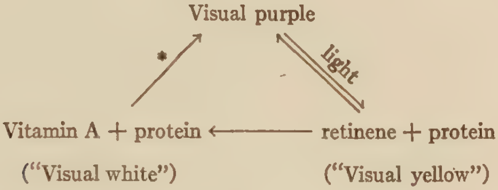
II. SEA ROBIN, SEA BASS, AND SCUP

BY GEORGE WALD

(*From the Woods Hole Oceanographic Institution, Woods Hole,*[*] *and the Biological Laboratories of Harvard University, Cambridge*)

(Accepted for publication, November 21, 1935)

In the preceding paper of this series (Wald, 1935–36 *b*) the visual purple system of the bull frog was found to conform in part with the equations:



in which all but the reaction starred occur in the isolated retina as well as in the intact eye.

Identical processes are found in the retinas of the sea robin (*Prionotus carolinus*), the black sea bass (*Centropristes striatus*), and the scup or porgy (*Stenotomus chrysops*). In the pigment epithelium and choroid layer of these fishes pigments occur also which are either identical with or very closely related to those in frogs.

Köttgen and Abelsdorff (1896) found the absorption spectrum of visual purple from amphibia, owls, and mammals to possess a maximum at about 500 mμ; while that from eight species of fresh water fishes, though of the same general form, is displaced so that its maximum occurs at about 540 mμ. This spectral peculiarity, if general, should lend special interest to an examination of the visual system in fishes. However, visual purple solutions from the three marine species discussed in the present paper have been found to be almost identical spectroscopically with those of frogs, the maxima occurring in each case at about 500 mμ. The apparent discrepancy between these and Köttgen and Abelsdorff's results is being investigated further.

---

[*] Contribution No. 83. I am greatly indebted to Professor Henry B. Bigelow and Mr. William C. Schroeder of the Oceanographic Institution for much friendly assistance in the preparation of these experiments.

Retinas

Experiments performed in the examination of frog retinas have been repeated with fish tissues with identical results. The dark adapted retinas contain a small quantity of free vitamin A and a large amount of bound retinene. The latter is liberated by destroying the visual purple, either with light or with chloroform. Retinene liberated by light is subsequently converted to vitamin A by a thermal reaction, evidenced by the fading of the visual yellow retina to colorlessness.

I shall not describe the details of these experiments again, but instead record a simple procedure which has served to establish the nature of the visual purple system in a single experiment. To follow this one need only recall that both retinene and vitamin A yield blue colorations when mixed with antimony trichloride reagent, due in the case of retinene to an absorption band at 662–666 mμ, in that of vitamin A to one at 612–615 mμ.

Figs. 1 and 2 show the results of this type of experiment performed with scup and sea robin retinas, Fig. 3 a slight variant of this procedure with bass tissues.[1]

Right and left retinas of five dark adapted fishes (scup and sea robin, 8 to 10 inches long) were prepared separately. One set of five retinas was extracted thoroughly in the dark with about 12 cc. of benzine in 4 portions, shaking violently by machine for a total of 20 minutes. The extract brought into chloroform was colorless and when tested with antimony trichloride yielded blue solutions of which Curves *a* of Figs. 1 and 2 are the absorption spectra. The dark adapted retina therefore contains a small quantity of vitamin A alone.

The same tissues were bleached subsequently in daylight to an orange color ("visual yellow") and were immediately re-extracted with benzine. The extract, brought into chloroform, was bright yellow. Tested with antimony trichloride it yielded Curves *b* of Figs. 1 and 2. The bleaching of visual purple to yellow therefore liberates a large quantity of retinene.

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[1] All spectra shown in this paper were recorded automatically with a photoelectric spectrophotometer (Hardy, A. C., *J. Opt. Soc. America*, 1935, **25**, 305) at the Massachusetts Institute of Technology.

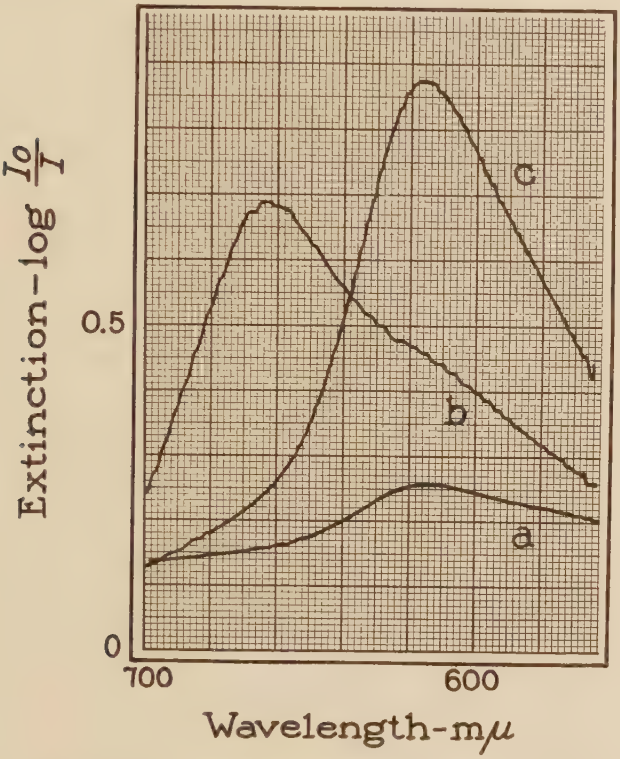

FIG. 1. Absorption spectra of the antimony trichloride reaction with benzine extracts of scup retinas. *a*, Dark adapted retinas; the extract contains a small quantity of vitamin A (615 mμ chromogen). *b*, The same retinas, re-extracted immediately after bleaching. A large quantity of retinene (664 mμ chromogen) has been liberated. *c*, Retinas from the same fishes, extracted 1 hour after bleaching. The free retinene has been converted to vitamin A.

The second set of five retinas was bleached in daylight and left at room temperature in moderate light for an hour. During this period the retinas faded from orange to colorlessness. They were extracted with benzine exactly as before. The extract, brought into chloroform, was colorless, and when tested with antimony trichloride yielded Curves *c* of Figs. 1 and 2. The fading process converts retinene liberated in bleaching quantitatively to vitamin A.

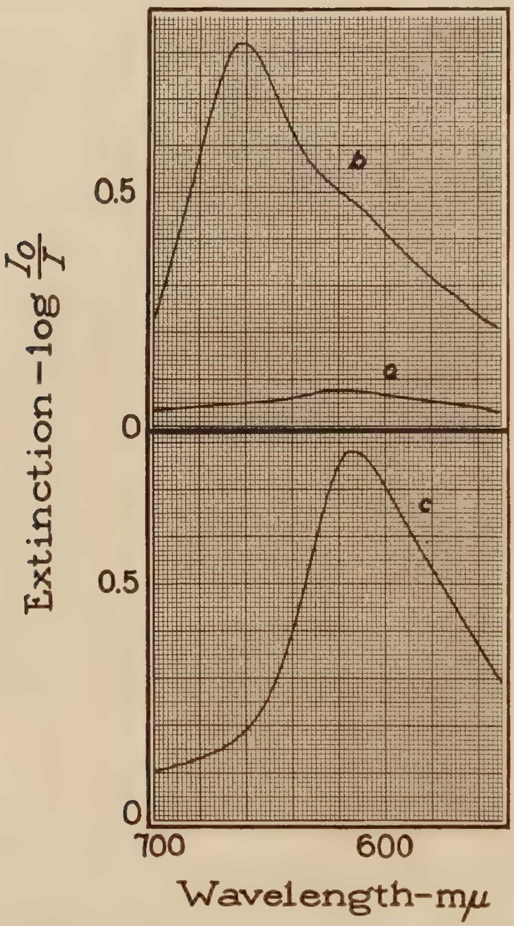

Fig. 2. Absorption spectra of the antimony trichloride reaction with benzine extracts of sea robin retinas. Compare with Fig. 1.

At the time of these experiments only 3 bass about 14 inches long were available. The retinas of two of these were used to prepare a visual purple extract. The residual tissue from this procedure still contained visual purple, which was destroyed by extracting with chloroform. The extract was yellow, and with antimony trichloride yielded the upper curve of Fig. 3, showing the presence of retinene and a small amount of vitamin A. The retinas from the single remaining fish were bleached in daylight and allowed to fade for an hour. They were then extracted with benzine. The colorless extract, tested with antimony trichloride, yielded the lower curve of Fig. 3, showing,

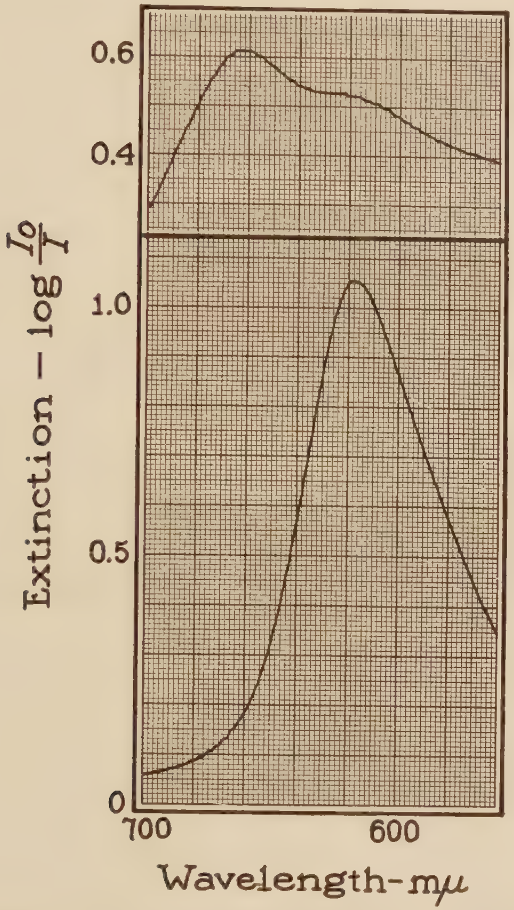

FIG. 3. Absorption spectra of the antimony trichloride reaction with extracts of sea bass retinas. *Upper curve,* chloroform extract of dark adapted retinas. *Lower curve,* benzine extract of bleached and faded retinas.

as in the other forms, the conversion of retinene liberated by light to vitamin A.

Maximal quantities of vitamin A occur in retinas which have been bleached and allowed to fade completely *in vitro*. These quantities, estimated roughly by a colorimetric method (Wald, 1935–36 *a*) are: sea robin, 1.4; scup, 2.8; and bass, 4.7 γ per retina. The retinal dimensions in the specimens used increased in the same order, so that it is possible that the quantity of vitamin A per unit weight of retina is approximately constant in all three species.

Acid-Base Effects upon the Visual Yellow Retina.—Characteristic responses of the visual yellow retina to acids and alkalies have been observed in frogs and fishes and examined in some detail in the sea robin. Chase (1935–36) has shown that a yellow product of the bleaching of visual purple in solution behaves as an acid-base indicator, turning colorless in alkaline solutions. This observation is closely related to those to be described. The behavior of the retinal pigments *in situ*, however, is much more complicated than in solution, and the precise connections between the two situations are still to be elucidated. At present certain features in the acid-base behavior of the sea robin retina may be indicated.

The bleached, visual yellow retina is of a distinctly orange color. When made sufficiently alkaline, it turns practically colorless; if made strongly acid, bright yellow. The change from yellow to colorless is freely reversible, the tissue behaving as an acid-base indicator. However, I have never succeeded in bringing such retinas back to the original orange color of visual yellow. Some irreversible change therefore accompanies these abnormal pH's.

The bright yellow, comparatively photostable material which is formed when the retina is treated with strong acids has long been employed as a test for visual purple (Boll, 1877; van Genderen Stort, 1887). In reality it is a test for retinene or visual yellow. It is yielded by dark adapted and visual yellow retinas, but not by retinas which have been bleached and allowed to fade completely; that is, in which the retinene has been converted to vitamin A. Since the acid yellow color is considerably deeper than that of neutral visual yellow, it reveals the presence of retinene in retinas which when neutral may appear quite colorless. In this way the last traces of retinene in the fading retina may be distinguished.

Neutral visual yellow retinas, cooled to 0°C., retain their color for hours, even in bright daylight. Such retinas may be titrated on ice with alkalies to determine the pH at which the color change occurs. In 0.035N NaOH or 0.35N NH_3 the orange retina loses its color within about 10 minutes at 0°C. in daylight. In more strongly alkaline solutions or at higher temperatures the reaction is more rapid. These time intervals are not needed primarily for penetration of the reagent, for a dark adapted retina soaked in 0.23N NH_3 for ½ hour in the dark before being exposed to light on ice, first turns orange and then still requires about 12 minutes to fade to colorlessness. This period is apparently principally occupied by the irreversible reaction which transforms visual yellow to the yellow-colorless pH indicator.

The pH at which the visual yellow retina is decolorized is well outside the physiological range. The concentrations of alkali cited above as approximately minimal correspond to pH's of about 11–12. In such solutions the tissue disintegrates rapidly. Dark adapted retinas, soaked for 10 minutes in phosphate buffers at pH 6.0 and 8.0 before being exposed to light, exhibited no detectable differences either in color before and after bleaching or in rates of bleaching, fading, and regeneration. A retina at pH 9.0 behaved similarly. The acid-base changes discussed above are therefore decidedly abnormal.

In ammoniacal retinas (0.23N NH_3) the colorless derivatives of visual yellow are not removed to form vitamin A, nor do they regenerate visual purple in the dark. Even after 3 hours in the light at room temperature their presence is revealed by the strong yellow color which develops when the retina is acidified. On the other hand the reversion of visual yellow itself to purple is greatly accelerated in 0.23N NH_3. Ammoniacal retinas, returned to the dark immediately after bleaching, before the visual yellow has been appreciably decolorized by the alkali, regenerate considerable amounts of visual purple within ½ hour even at 0°C., though at this temperature neutral retinas do not change appreciably within a comparable period. Curiously, the ammoniacal visual yellow retina regenerates more visual purple at 0°C. than at room temperature. It seems as though two reactions compete for the removal of visual yellow—reversion to purple, and the irreversible formation of the pH indicator; and that the former is relatively favored at low temperatures.

The accelerating effect of NH_3 upon the reversion process explains Kühne's observation, which I have confirmed, that the ammoniacal retina bleaches more slowly than the neutral tissue (Kühne, 1878). This difference cannot be ascribed to induced photostability in the visual purple itself; for ammoniacal visual purple *solutions*—in which appreciable reversion does not occur—bleach much more *quickly* than neutral solutions. This is true also of solutions buffered at pH 9.3 (Chase, 1935–36), so that it is a general alkaline effect and not one restricted specifically to ammonia.

Pigmented Layers

The combined pigment epithelia and choroid layers of these marine fishes contain vitamin A, flavine, and an unidentified xanthophyll.

Flavine was first found in fish pigment epithelia by von Euler and Adler (1934); nothing in the present investigation adds materially to the description of it given by these authors. The spectrum of flavine from bass pigmented tissue is shown in Fig. 4.

Fish xanthophyll is spectroscopically different from that found in frogs, and so will be described in some detail. It occurs in the tissues as an ester: when partitioned between 90 per cent methanol and benzine, it accumulates in the benzine layer before and in the methanol layer after saponification. It is readily extracted from strongly alkaline aqueous alcohol with benzine. The free pigment is strongly adsorbed on a column of calcium carbonate, forming a golden layer. These are general properties of the hydroxycarotenoids or xanthophylls.

In CS_2 the pigment possesses absorption maxima at 439, 470–472, and 500–501 mμ. A scup preparation diverged slightly from this, showing bands at 439, 476, and 502 mμ; but this spectrum was unusually diffuse as though the pigment had deteriorated in solution. The spectrum of free xanthophyll from bass is shown in Fig. 5.

In general form these spectra resemble those of the dihydroxycarotenoids, $C_{40}H_{56}O_2$. The band positions, however, are closest to those of violaxanthin and taraxanthin, isomers of composition $C_{40}H_{56}O_4$. Violaxanthin yields a blue color when treated in ether with 25 per cent HCl. A single trial of this test with a sea robin extract was negative, possibly due to low concentration of the pigment.

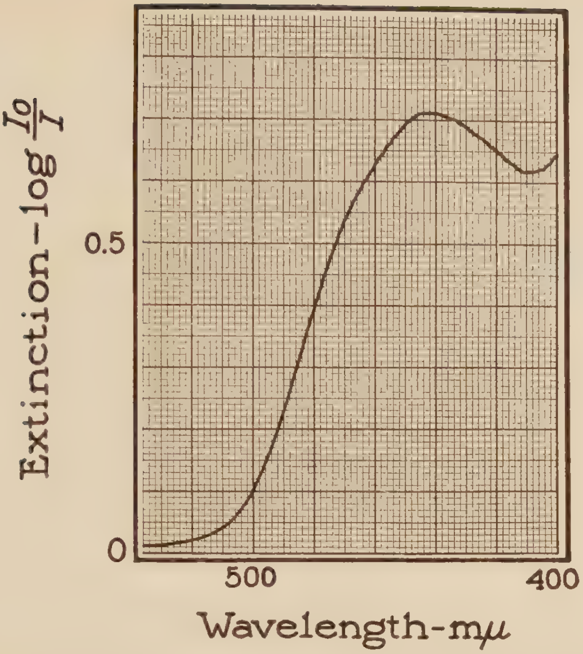

FIG. 4. Spectrum of an aqueous solution of flavine from sea bass pigmented layers.

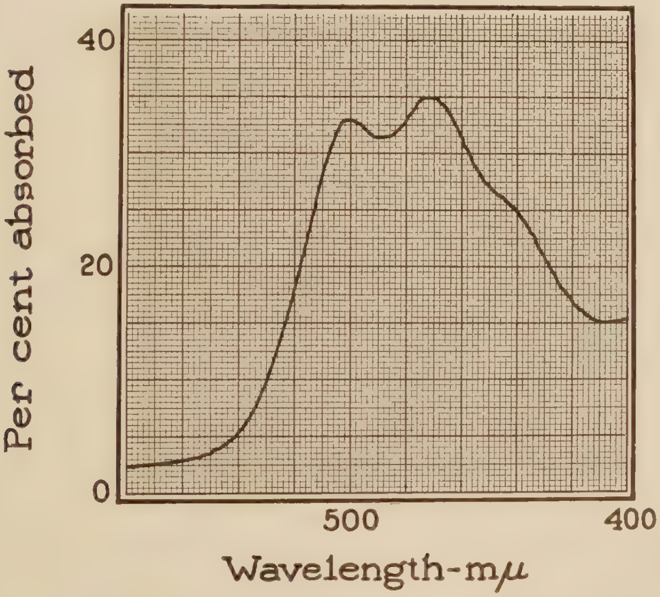

FIG. 5. Spectrum of free xanthophyll in CS_2 from sea bass pigmented layers. The non-saponifiable portion of the crude extract had been partitioned between benzine and 90 per cent methanol. The methanol fraction is shown.

The distribution of the fish pigments between benzine and various concentrations of methanol is identical in all three species. No appreciable quantity of pigment leaves the benzine for 70 per cent methanol, a minor proportion does so for 80 per cent methanol, and practically all of it goes into 90 per cent methanol. This behavior is typical, and, indeed, roughly specific for the dihydroxycarotenoids.

The relative solubilities of xanthophylls in polar solvents like methanol compared with non-polar solvents like benzine rise rapidly with the number of oxygen atoms in the molecule. This relation is shown in Table I, compiled from various portions of Zechmeister's monograph (1934); the behavior of the $C_{40}H_{56}$ carotenes is included. The terms epiphasic and hypophasic refer respectively to pigment solubility in the upper, benzine, and in the lower, alcoholic layers.

TABLE I

Carotenoid	Partitioned between benzine and —	Behavior
$C_{40}H_{56}$	90 per cent methanol	Almost wholly epiphasic
$C_{40}H_{56}O$	95 per cent methanol	Partly hypophasic
$C_{40}H_{56}O_2$	90 per cent methanol	Almost wholly hypophasic
	70 per cent methanol	Almost wholly epiphasic
$C_{40}H_{56}O_3$	" " "	Slightly (1/9) hypophasic
$C_{40}H_{56}O_4$	" " "	More (1/6) hypophasic
$C_{40}H_{56}O_6$	" " "	Almost wholly hypophasic

The fish pigment therefore resembles the $C_{40}H_{56}O_2$ xanthophylls. Its spectrum, however, is almost uniformly displaced 4–7 mμ below that of lutein, the most similar known xanthophyll of this composition. More specific identification of the fish pigment, only very small quantities of which were available in impure condition, is at present impossible.

Cunningham and MacMunn (1893) and Lönnberg (1933–34) have found carotenoids in the skins, fins, and other tissues of a large number of species of marine fishes. The species investigated by Lönnberg form two groups, one in which the carotenoids resemble lutein spectroscopically, and an equally large group in which the spectra are displaced 4–6 mμ toward shorter wavelengths. It is not improbable that the second type of pigment is identical with that found in the present investigation.

Sumner and Fox (1933) have found that the carotenoid pigments of superficial and deep structures in four species of marine fishes are exclusively of the xanthophyll series. It seems that, as in the frog, these pigments are generally distributed about the organism, and that their presence in the pigmented layers of the eye is probably of no special significance.

Rough estimates of the quantities of xanthophyll, vitamin A, and flavine in the pigmented tissues are presented in Table II. These were measured with a Pulfrich photometer in the manner already described (Wald, 1935–36*a*, *b*). In the case of xanthophyll, the same factor for converting photometer readings into absolute units was used as in the frog, since Kuhn and Brockmann (1932) have shown that a number of xanthophylls have approximately the same depth of color.

TABLE II

Fish	No. of eyes	Xanthophyll per eye	Vitamin A per eye	Flavine per eye
		γ	γ	γ
Sea robin	14	1.0	Trace	9
Scup	20	0.56	0.8	18
Sea bass	6	3.0	5	28

SUMMARY

1. Visual purple from the sea robin, sea bass, and scup is almost identical spectroscopically with that from frogs. The interrelations of this pigment with vitamin A and retinene are also the same as in the frog.

2. In strong acids or at pH > 11, the visual yellow of sea robin retinas is converted irreversibly into a pH indicator, yellow in acid and almost colorless in alkaline solution. Unlike neutral visual yellow, the indicator is not removed to form either vitamin A or visual purple. In the ammoniacal retina the reversion of visual yellow itself to purple is accelerated.

3. The combined pigment epithelium and choroid layer in these fishes contain vitamin A, flavine, and an unidentified xanthophyll.

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Contribution No. 84

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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GEOLOGY AND PALEONTOLOGY OF THE GEORGES BANK CANYONS

Part III. CRETACEOUS BRYOZOAN FROM GEORGES BANK

BY R. S. BASSLER

Among the specimens dredged from Georges Bank in 1934 and submitted for determination was a fairly well-preserved, ramose cyclostomatous bryozoan belonging to the unusual genus *Plethopora* Hagenow, 1851, of the Cytisidae, species of which have hitherto been found only in the Cretaceous of Europe. In this genus the solid, cylindrical, branching zoarium consists of angular thin-walled tubes grouped in salient fascicles, or bundles, projecting at the surface in knobby elevations, or ridges, and separated by numerous nematopores, the adventitious, thread-like, angular, thin-walled, upwardly directed tubules. In the type of the genus, *P. verrucosa* Hagenow, from the Maestrichtian of Holland, the bundles of tubes open at the surface in elongate, rounded nodes; but in the present species the bundles are more elongate, narrow, and occasionally branched.

Plethopora americana Bassler n.sp.

(Stephenson, Plate 1, figure 18)

Description.—Zoarium cylindrical, slightly flattened, with branches 3 to 4 millimeters in diameter, dividing dichotomously at more or less regular intervals of 10 millimeters, with surface occupied by narrow, elongate, sometimes branching bundles of fascicles of zooecia, separated by similar areas of very minute pores. The zooecia are small, thin-walled, angular, with 9 to 10 in one millimeter, and 5 or 6 rows in a fascicle. The very minute openings of the interfascicular spaces have the characteristic structure of nematopores. The fascicles proceed in a more or less indefinite way, on opposite sides of the zoarium, from a continuously developed wide central area of nematopores.

Remarks.—This, the first species of the genus ever discovered in America, is well marked by its very elongate, narrow, branching fascicles, which probably projected above the surface, although the type specimen is worn and does not show this character. *Plethopora cervicornis* D'Orbigny, 1852, from the Senonian of Tours, France, is similar, but the branches divide at long intervals, and the fascicles are arranged on more regular enveloping bands.

Type.—Holotype, Museum of Comparative Zoology (M.C.Z. 8761), Harvard College, Cambridge, Massachusetts.

Occurrence.—Atlantic Ocean, Georges Bank, Latitude N. 40°24′30″, Longitude W. 68°07′30″; dredged from between depths of 480 and 596 meters.

Geologic position.—Upper Cretaceous (Senonian).

U. S. National Museum, Washington, D. C.

Manuscript received by the Secretary of the Society, October 18, 1935.
Read before the Geological Society, December 27, 1934. (Presented by Stetson, as part of the general problem, *see* p. 339.)
Contribution No. 84, Woods Hole Oceanographic Institution.

Contribution No. 85

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THE BIOLOGY OF CALANUS FINMARCHICUS IN THE GULF OF MAINE AND BAY OF FUNDY

CHARLES J. FISH

(*From the Woods Hole Oceanographic Institution, Woods Hole, Mass.*[1])

Introduction and Methods

The problem considered in the present paper concerns the production and dispersal of *Calanus finmarchicus* in a partially enclosed body of water. There have been two principal objectives; first, a determination of the breeding seasons, annual number of broods, rate of growth and length of life; second, an evaluation of different spawning areas, and dispersal of eggs and larvæ.

Monthly cruises were made from July 28, 1931 to September 29, 1932 in the Bay of Fundy and from April to September, 1932, in the inner part of the Gulf of Maine, with one cruise in the outer Gulf and along the south coast of Nova Scotia, yielding in all a total of 838 zoöplankton samples (Fig. 1). In August 1931 one line of stations was taken in the Gulf.[2]

For convenience in description, the region has been subdivided into four areas shown in Fig. 1. For the sampling of eggs and immature stages, the pump was used during the summer, a volume of 250 liters of water from each of four levels, 0, 10, 30, and 50 meters being filtered at each station. Analyses were made by the Sedgewick-Rafter counting method, and the number of individuals per cubic meter calculated. In determining horizontal distribution, in the present report, the value taken for each station represents the mean of the four levels. Until weather conditions permitted the use of the pump (end of June), half-meter nets (two meters in length) of No. 10 silk were utilized. The hauls were of 15 minutes duration and were oblique from 50 meters to the surface, the distance being divided into six steps at intervals of 10 meters each. The counts were made by the same method used in the pump samples, but the number of organisms per minute of towing was taken as the unit of measure.

Importance

Calanus finmarchicus is the most abundant animal in the Gulf of Maine, occurring offshore throughout the year and well into inshore waters except during the warm summer months when its distribution is somewhat variable. In Frenchmans Bay, with temperatures as low as 7–9° C. persisting in the lower levels, it was found abundant throughout the summers of 1929, 1930, and 1932, but in shallower or more turbulent estuarine areas such as Passamaquoddy Bay, where the whole water mass responds more rapidly to seasonal warming (10–12° C. after August 1), *Calanus* was comparatively sparse between June and October.

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[1] Contribution No. 85.

[2] Investigations for the International Passamaquoddy Fisheries Commission.

FIGURE I

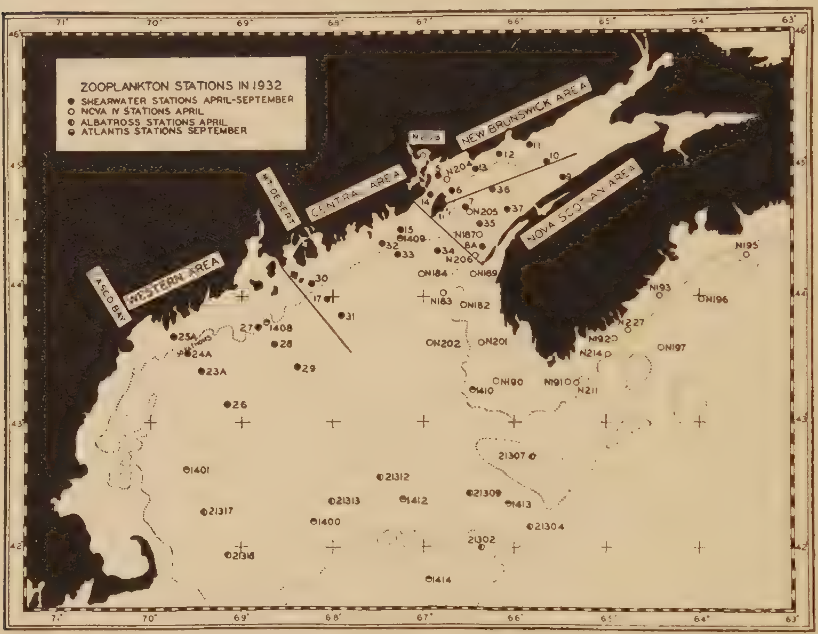

Fig. 1. Zoöplankton stations in 1932.

Its importance in the region is indicated in Tables I and II giving the relative percentage by number of *C. finmarchicus* to the total zoöplankton population. Within the Bay of Fundy, *Calanus* was found most abundant at all times in the vicinity of the deep basin, with year values increasing upon approaching the entrance. Thus, as indicated below, at Station 5 in the Quoddy region the mean for the year was 32.4 per cent, at Station 6 east of Grand Manan 37 per cent, and at Station 8A near the mouth on the Nova Scotian side, 41.8 per cent.

In the Gulf of Maine the highest values occurred in the central area where production of many of the pelagic species breeding during the summer appears to be largely unsuccessful. Here *C. finmarchicus* ranged from 40 per cent to 90 per cent, except in April when locally spawned larvæ of *Balanus balanoides* dominated the hauls.

Bigelow (1926, p. 199) found that in the Gulf of Maine *Calanus* averaged approximately 55–60 per cent of the total copepod content. In 1932 it averaged 60.4 per cent of the zoöplankton population in May with a total copepod content of 77.2 per cent and 39.9 per cent for the period April to September. In the eastern Atlantic Ruud's (1929, p. 11) records indicate that off Möre in 1926 and 1927 *C. finmarchicus* formed about 13–15 per cent of the copepod population in March and rose to 63.4 per cent following vernal augmentation. The average for the period March–July during the two years was approximately 39 per cent.

Table I

Relative percentage by number of *C. finmarchicus* to the total zoöplankton population, 1931–32, Bay of Fundy.

1931–32	Bay of Fundy			
Month	Mean	Station 5	Station 6	Station 8A
September	28.5	17.5	6.7	61.4
October	23.4	23.4	—	—
November	31.3	36.1	34.6	23.3
December	37.9	61.2	34.2	18.2
January	25.9	25.9	—	—
March	61.6	73.2	57.3	54.4
April	34.8	49.7	36.6	18.1
May	41.0	4.8	56.7	61.5
June	36.4	15.5	42.5	51.2
July	29.0	29.0	—	—
August	31.4	20.0	27.8	46.3
Mean for year	35.5	32.4	37.0	41.8

It would thus appear that in the Gulf of Maine *C. finmarchicus* forms a more important member of the zoöplankton population than in the region off Möre, although at no time were eggs found in such quantities as reported from certain areas between Norway and Iceland, where Damas (1905, p. 12) found them at times comprising practically the entire haul. In the Gulf of Maine at the peak of June spawning (1932) eggs of *Calanus* were the dominant form, but were everywhere outnumbered by the combined eggs and larvæ of other species. In the Bay of Fundy, also, Willey has commented (1921, p. 189) on the absence of *Calanus* eggs in any such relative abundance as reported by Damas. However, the importance of this species is evidenced by the manner in which the total volume of zoöplankton follows the fluctuations in the *Calanus* content (Fig. 2), a condition also noted by Ruud (1929, p. 12) for the Möre area.

Regional Distribution of the Adult Stock

The quantitative distribution of adult *C. finmarchicus* (including late copepodite stages) in the Gulf of Maine as described by Bigelow (1926, p. 188) accords so closely with present data that little need be added here. Although almost everywhere abundant, Bigelow found marked horizontal variations. Together with other boreal plankton animals the smallest numbers were found in 1931 and 1932 in the Bay of Fundy, particularly on the New Brunswick side, and along the adjacent coast of Maine to Penobscot Bay. However, although the values were uniformly low, due to equally small numbers of other boreal zoöplankton species, *C. finmarchicus* is relatively almost as

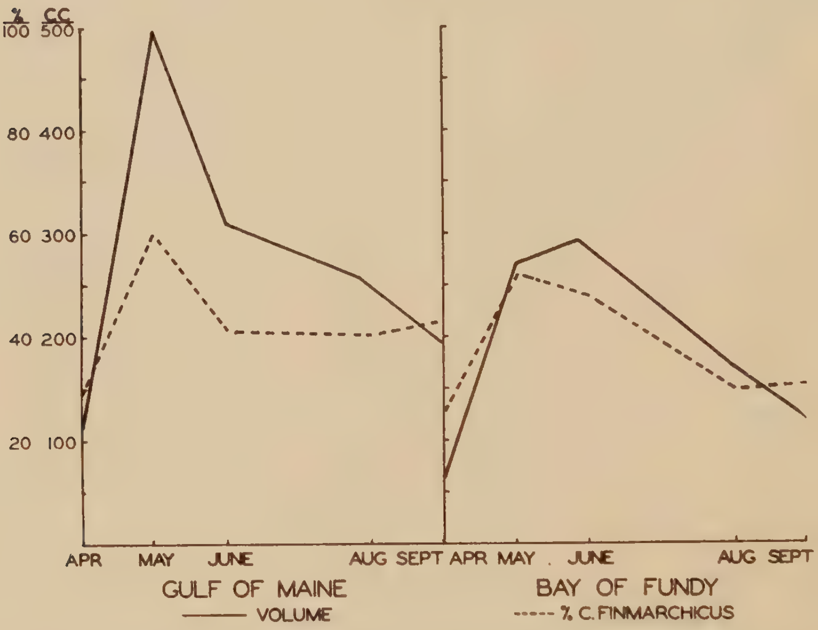

Fig. 2. Volume of zoöplankton and relative percentage by number of *C. finmarchicus* (adults and late copepodites) in the Gulf of Maine and Bay of Fundy in 1932.

important a member of the population in this region as elsewhere in the Gulf. The largest numbers in the Bay of Fundy occurred in the deep basin and along the Nova Scotian coast; in the Gulf of Maine, at the outer stations.

PRODUCTION AND DISPERSAL

Propagation of *Calanus finmarchicus* has been found to vary greatly in different localities, both in the rate of development and the number of broods. Available records indicate that in the southern portion of its range development is relatively rapid and spawning may begin as early as January. Proceeding northward into colder water, the period of vernal augmentation becomes increasingly later, development slower, and there are fewer broods.

In the Clyde Sea, a fairly enclosed basin with a mean annual temperature of over 10° C. and minimum holothermic temperatures in the spring of 5–7° C. (Chumley, 1918, p. 14),[3] eggs and nauplii of *C. finmarchicus* were found by Nicholls (1933, p. 89) in January, followed by three well defined breeding periods, February–March, April–May, and June–July, with additional subsidiary broods of lesser importance in July and August. These broods represent successive generations, the adults dying off after spawning.

TABLE II

Relative percentages by number of *C. finmarchicus* to population of total region of Bay of Fundy, and of Gulf of Maine in 1932.

1932	Total region	Bay of Fundy	Gulf of Maine		
			Total gulf	Western area	Central area
April	25.7	24.6	26.8	34.9	18.7
May	56.4	52.4	60.4	66.0	54.8
June	44.7	47.5	41.9	44.4	39.4
August	35.6	29.8	41.4	39.4	43.3
September	37.3	30.7	43.9	43.2	90.2
April–September	39.9	37.0	42.9	45.6	49.3

In Norwegian waters off Möre, Ruud (1929) found propagation beginning in late March to early April, the maximum having passed by May both in 1926 and 1927. A second smaller maximum appeared in June and continued until late July. His records also indicate that spawning takes place earlier farther south and proceeds northward along the Norwegian coast where augmentation in spring and early summer (April–June) had previously been reported (Gran, 1902; Damas, 1905; Damas and Koefoed, 1907, etc.).

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[3] In the Gulf of Maine there is a mean annual temperature of 7–8° C. and a minimum holothermic temperature of about 2° around the margin.

In the region of Iceland, Paulsen (1906, pp. 19–20) reported the principal propagation season of *C. finmarchicus* to be from March until June with a possible second reproduction period later. At the meeting point of the Atlantic and North Polar currents, south of 67° N, the season is in late June (Damas, 1905), and east of Greenland, in late July (With, 1915).

In the Gulf of Maine and Bay of Fundy previous investigations have shown the stock of *Calanus* to be at a minimum in late February and early March, at which time regional differences would be expected to be least. Vernal augmentation begins in late March and April (depending on the locality) and varies somewhat from year to year. Early nauplii were abundant in Massachusetts Bay by April 7 in 1925 (Fish, 1928, p. 286). In coarse net hauls where the effect of production would not be noted until the new stock had reached copepodite stages, Bigelow (1926, p. 192) observed in 1920 a slight increase from March to April in the coastal zone between Cape Cod and Mt. Desert, a considerable increase in Massachusetts Bay (× 400), and in the western basin about the same average number as in February and March. His data of several years led him to conclude that probably the "multiplication of *Calanus* does not proceed so rapidly in the northern parts of the Gulf, though it may commence there as early as mid-April" (Ibid, p. 194). There was also evidence that breeding probably continues actively through June, and an increase in the numbers of *Calanus* in September suggested a second but less productive season in early autumn (Ibid, p. 207).

To the north Willey (1919) found evidence of vernal propagation over a broad area between Nova Scotia and Newfoundland. At the eastern end of St. Pierre Bank in 1915 *Calanus finmarchicus* in copepodite stages II–V was taken on June 24 and again on July 27. Stages III–VI were also obtained south of Cabot Strait on July 27 and in the Laurentian Channel on July 28.

Distribution of Eggs and Larvæ in 1932

An analysis of propagation in the Gulf of Maine and Bay of Fundy is complicated by the progressive delay in seasonal response from west to east (Fig. 3) combined with an active cyclonic drift, which renders it difficult to ascertain the source of larvæ taken in any particular locality. Fortunately an average difference of approximately one month in the time of spawning in the eastern and western parts of the Gulf made it possible to distinguish two breeding stocks, and, through the distribution of dominant developmental stages in successive months, trace in a general manner the rate of growth and subsequent dispersal in each.

April.—Spawning must have begun in March, and by late April had terminated over the greater part of the Gulf. The more advanced larvæ had then reached the third and fourth copepodite stages, and were rather widely distributed in relatively small numbers. Nauplius stages IV–VI predominated in the Casco Bay region where production

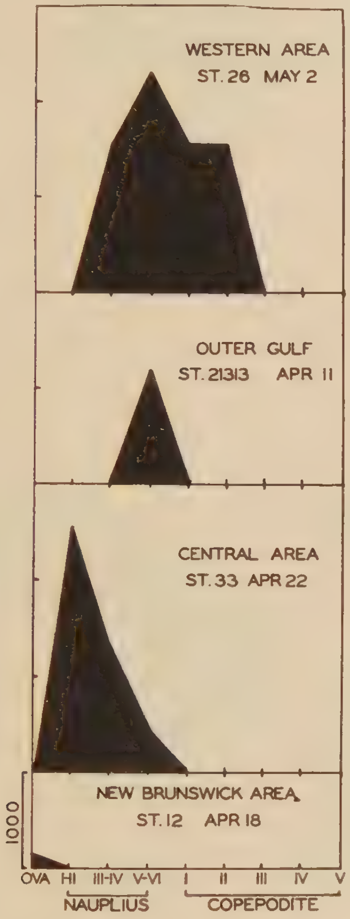

FIG. 3

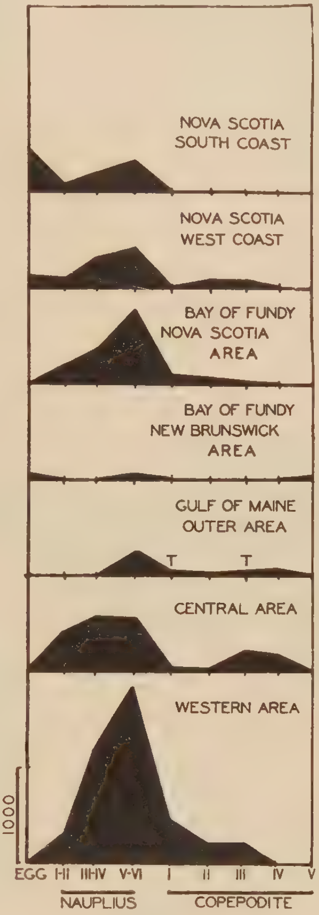

FIG. 4

FIG. 3. *Calanus finmarchicus*, showing progressive delay in seasonal response to the eastward, and evidence that the larval stock in the outer Gulf may have originated in the western area.

FIG. 4. *Calanus finmarchicus*, showing nauplius stages IV–VI dominating throughout the region in April 1932. (Average of all stations in each area.)

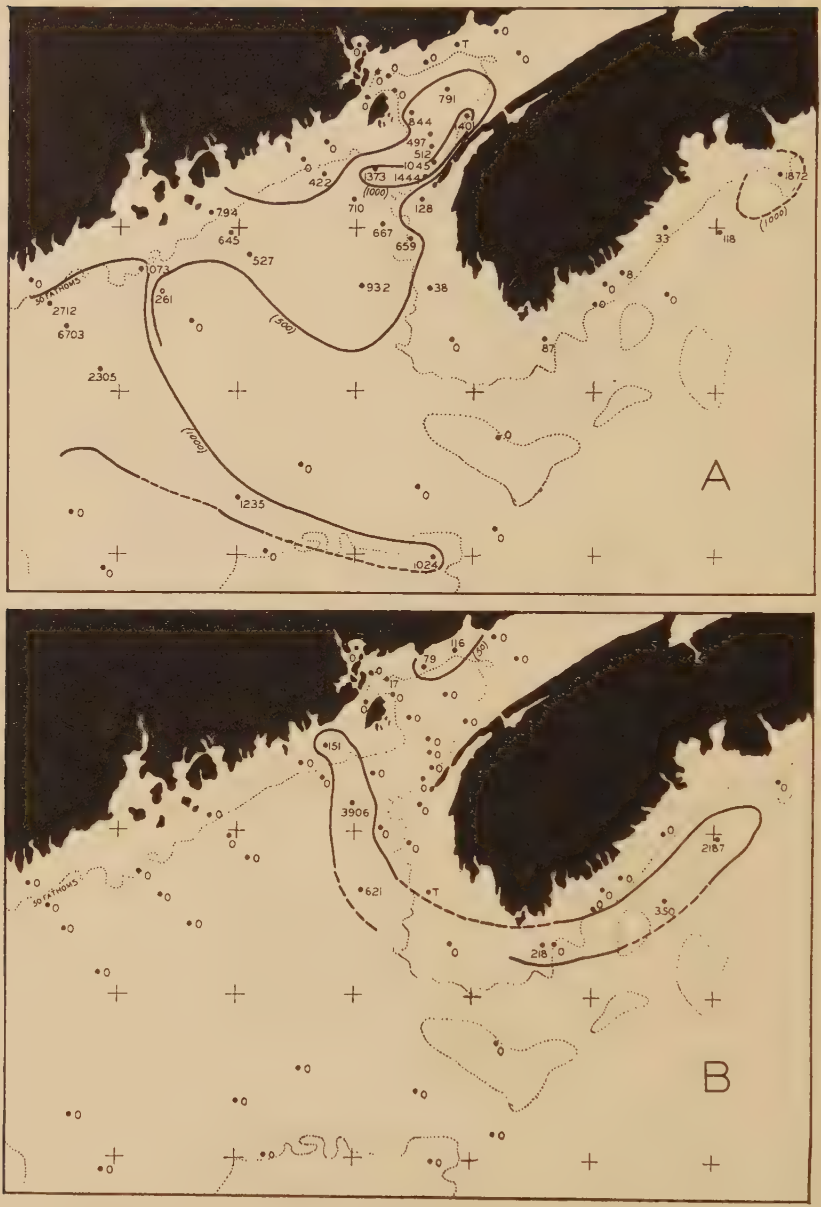

FIG. 5. Distribution of (*A*) nauplius stages V–VI of the western stock, and (*B*) eggs of the eastern stock in April 1932. Number per minute of towing.

was so much more extensive than elsewhere that its contributions outnumbered locally produced larvæ over the greater part of the Gulf and Bay, a condition which continued throughout the summer. As it was possible to make but one series of observations in the outer Gulf, the duration and extent of propagation in that area could not be determined, but the distribution of larvæ, consisting of nauplius stages V–VI with a small number of copepodite stage III and no intermediates, would suggest the western coastal area as the principal source. However, a local concentration of nauplius stages V–VI off Nova Scotia offers positive evidence that in outside waters the season was as far advanced off Halifax as in the region of Casco Bay. Between these two areas, along the south and west coasts of Nova Scotia, the season appeared to be less advanced, more closely corresponding to the eastern part of the Gulf where spawning had not yet ceased.

TABLE III

Maximal numbers of *Calanus finmarchicus* in various developmental stages in the western area of the Gulf and the Bay of Fundy, May, 1932.

Locality	1932	Ova	Nauplius			Copepodite				
			I–II	III–IV	V–VI	I	II	III	IV	V
Western area (Station 26).........	May 31			1029	515	1029	3603	8234	4117	2058
Bay of Fundy (Station 36)...........	May 22	669	1338	6021	8697		1338	669		

Eggs of the eastern breeding stock were found in varying abundance in the central area, the Bay of Fundy, and off the west and south coasts of Nova Scotia, but not west of Mt. Desert or in the vicinity of Georges Banks.

May.—By the latter part of May, as indicated in Table III, the maximum numbers of larvæ from the western area were in copepodite stage III, and the local crop east of Mt. Desert, in nauplius stages V–VI, the latter corresponding to conditions in the western area a month earlier. In Fig. 6A late larval stages are seen to extend eastward from the rich Casco Bay region in a band whose inner margin parallels the 100-meter contour. They also penetrated in a tongue-like wedge into the Bay of Fundy along the Nova Scotian side, and show as a distinct second maximum in curves from both the Fundy and central areas (See Fig. 8, May sections off Cape Spencer, and Mt. Desert; also Table III, Station 36). These late copepodites of *Calanus finmarchicus* now dominated the total population and accounted largely for the tremendous rise in the volume of zoöplankton from April to May (Fig. 2).[4] Due to dispersal from the western area volumes everywhere increased, the increase being least noticeable in areas where

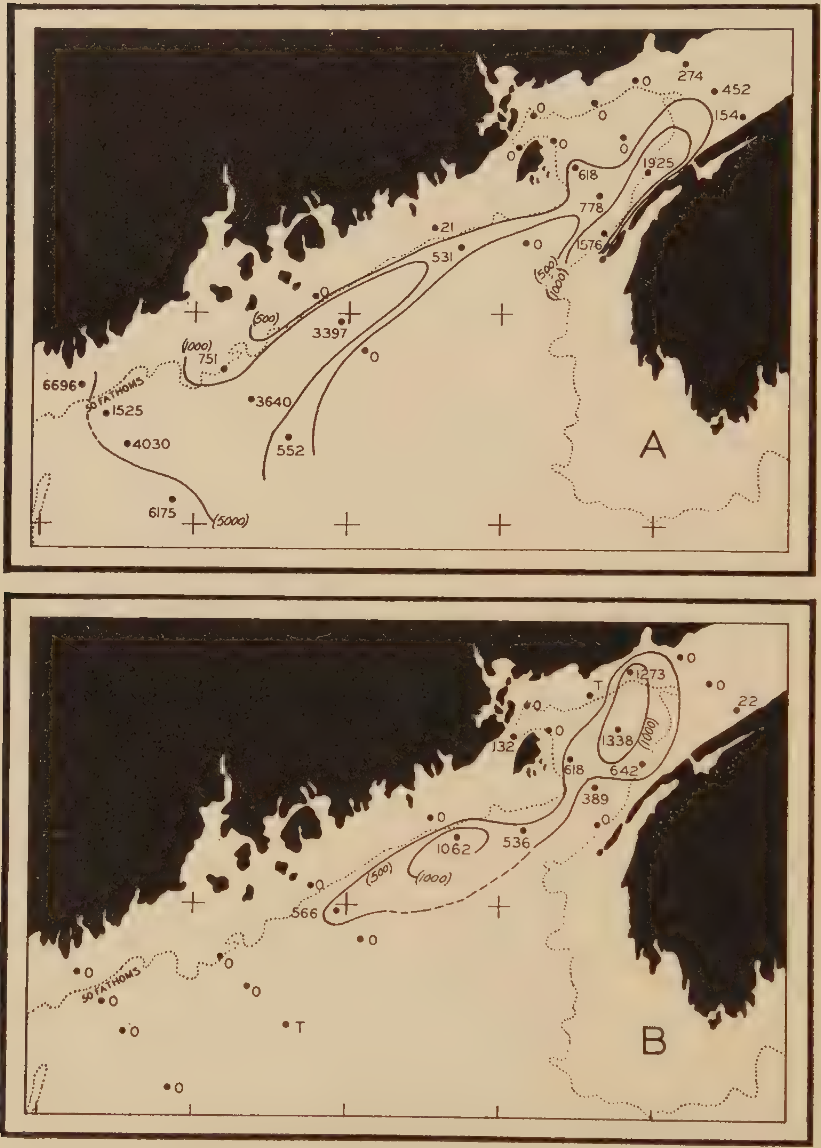

FIG. 6. Distribution of (*A*) copepodite stages IV–V of the western stock, and (*B*) nauplius stages I–II of the eastern stock in May 1932. Number per minute of towing.

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[4] Bogorov (1933) records an increase in the biomass (weight) of almost 60 times from copepodite stage I to stage VI.

the immigrant stock was not supplemented by a significant amount of local propagation. Particularly in the eastern coastal and New Brunswick regions, individuals of the local brood were not of sufficient size to be taken in the coarse meter nets in May.

Although late nauplii dominated in the eastern Gulf stock, some spawning must have continued well into May in the coastal waters east of Petit Manan, because early nauplii (I–II) were still numerous in this region between May 18 and 24 (Fig. 6*B*).

June.—The first western crop had matured and were spawning by June 20. As eggs were everywhere abundant (Figs. 7*A* and 8), although the eastern brood was still in copepodite stages (Fig. 9), the parent stock in all probability consisted almost entirely of individuals dispersed from the western area. In the eastern basin it is possible that the adults breeding at this time may have been reinforced to some extent from production centers outside of the Gulf, a possibility suggested by Bigelow's (1926, p. 209) records of a swarm of adults in this region on May 6, 1915, and the fact that in 1932 the largest single capture of eggs (25,321 per minute) was made in the eastern basin in June.

The eastern spring brood, in copepodite stages in June (Fig. 7*B*), were most numerous off Penobscot Bay and along the course of the drift into the Bay of Fundy. Elsewhere in the Bay and over the greater part of the central area, no copepodite stages were found, indicating that this brood suffers heavy mortality and only those produced in or transported as far as the western part of the central area survive.

August.—On August 11 in the Casco Bay region, after an interval of 42 days, the product of June spawning of the western stock, now in copepodite stages (III predominating), had been largely dissipated and the relatively few taken were distributed along the outermost stations from Casco Bay to the eastern basin. Elsewhere in the Gulf and Bay their numbers were extremely sparse.

Contrasted with copepodites of this second western crop, eggs and early larvæ, assumed to represent spawning by the first eastern brood, were concentrated nearer the coast. Early nauplii were most abundant in the Bay of Fundy (Station 7) and central area, with smaller numbers occurring westward at the inner stations to Casco Bay.

September.—It was not possible to obtain data from the Gulf of Maine in September, but stations in the Bay of Fundy yielded small numbers of eggs, early nauplii (stage I) and copepodites in stage II. The latter were probably the product of August spawning by a second eastern brood and the former, in view of the absence of eggs and early larvæ along the New Brunswick coast and their concentration in the course of the drift along the Nova Scotian coast and over the deep basin in the Bay of Fundy on September 15, suggest a third generation of the western stock entering from the Gulf.

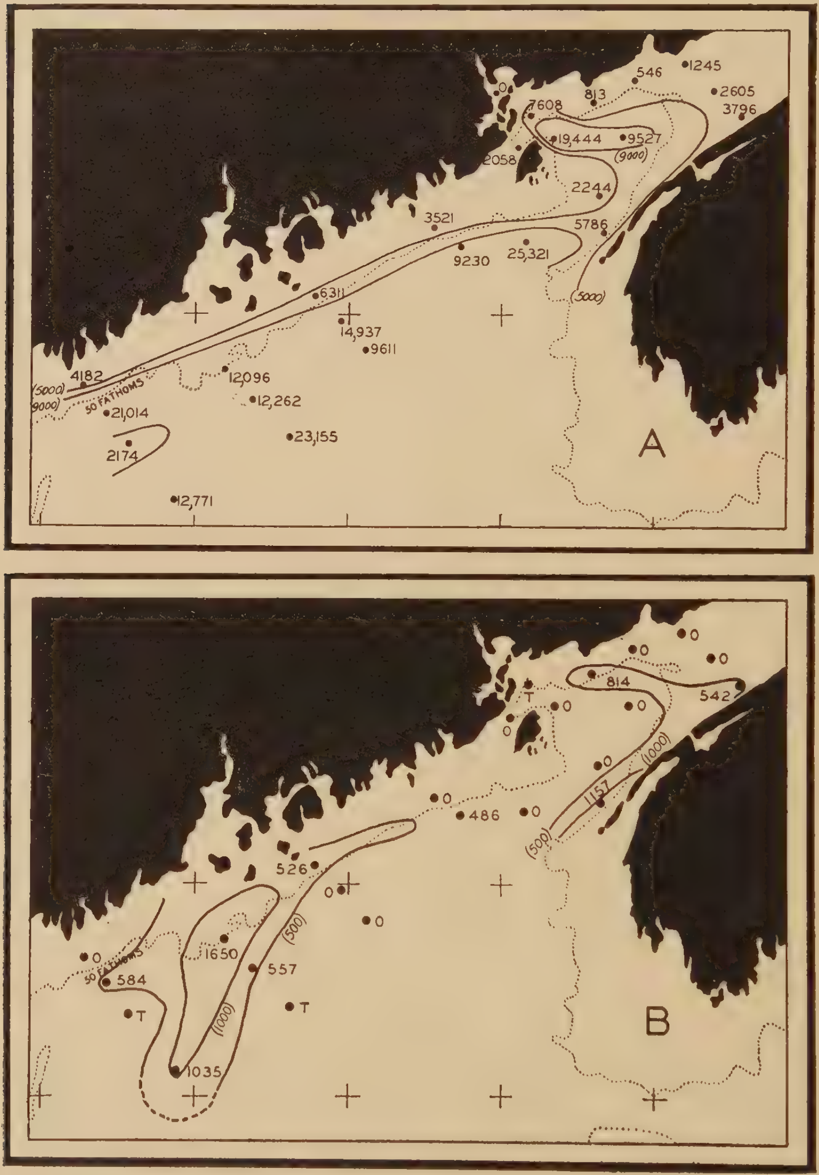

FIG. 7. Distribution of (*A*) eggs of the western stock, and (*B*) copepodite stages I–V of the eastern stock in June 1932. Number per minute of towing.

Comparison of Results in 1931 and 1932

In 1931 but one set of observations was made in the Gulf and Bay (August 21–September 5), corresponding stations being taken about two weeks later than in 1932 (August 8–21).

The season appears to have been about the same in the western area during the two years because a maximum of eggs between August 11 and 14 in 1932 would undoubtedly have hatched by August 21 when early nauplii were found predominating in 1931.

East of Mt. Desert, as the relative percentage of eggs and nauplii were much the same in the Nova Scotian and New Brunswick areas on August 17–21 in 1932 as on September 1–5, the spawning season would appear to have been about two weeks later in the previous year. Not having hydrographic data from the eastern basin of the Gulf for 1931, it is not possible to suggest a reason for the retarded season that year. Temperatures within the Bay of Fundy in 1931 and 1932 were not substantially different at this time.

Discussion and Conclusions

Throughout the Gulf of Maine and Bay of Fundy propagation begins in the spring and is followed by a succession of generations until autumn. The marked regional differences in the time when vernal augmentation begins are reflected through succeeding generations of that summer, irrespective of where the stock may become distributed. Thus by the time (June) that the spring crop from the western area has matured and spawned, it has become so generally distributed that eggs appear almost simultaneously throughout the Gulf and Bay (Fig. 8). Again, in July and August, when the smaller eastern vernal crop spawns, eggs appear in even greater abundance in the western area than in the region where the stock originates.

Propagation of the Stock Originating West of Mt. Desert in the Spring

The seasonal distribution of eggs and larvæ indicate two clearly defined spawning periods, March–April and June–July with a possible third in September. It is probable that most of the June–July brood remains in copepodite stages to form the bulk of the winter stock (maturing the following spring), but some appear to pass through the final moult and spawn in September.

The maximum numbers of larvæ of the first generation, which by late April in 1932 were in nauplius stages IV–VI, and in copepodite stage III thirty days later, had matured and were spawning by June 20.

The second generation is not as clearly traceable, but what are believed to have been members of the June brood were mainly in copepodite stage III forty-five days later on August 11 (Fig. 8, section *A*), and some became spawning adults by September 15 (p. 129).

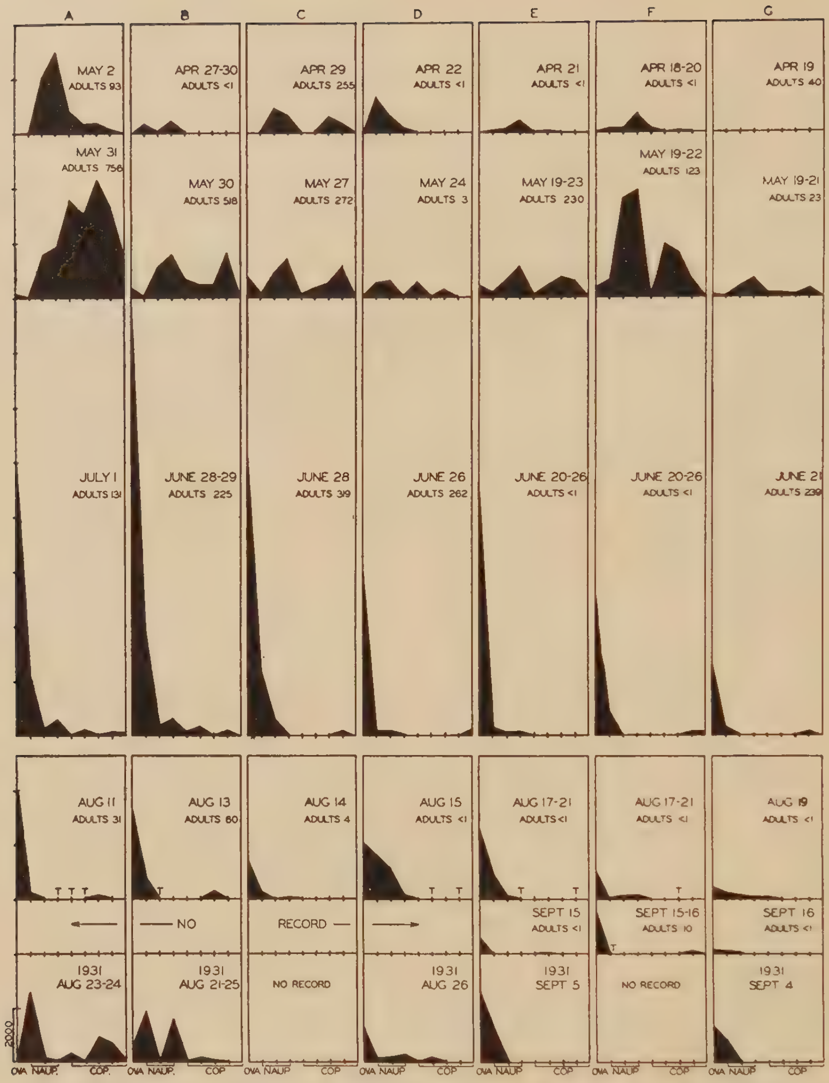

FIG. 8. Seasonal changes in the composition of the population of *Calanus finmarchicus* (developmental stages) in seven sections between Casco Bay and Cape Spencer.

Stages recorded as ova; nauplii I–II, III–IV, V–VI; copepodites I, II, III, IV, V.

Sections: *A*. Casco Bay (Stations 23*A*–25*A*, 26)
B. Penobscot Bay (Stations 27–29)
C. Mt. Desert (Stations 17, 30–31)
D. Moose Peak (Stations 32–33)
E. Passamaquoddy Bay (Stations 5–8*A*, 35)
F. Pt. Lipreau (Stations 13, 36–37)
G. Cape Spencer (Stations 9–11).
April–June: number per minute of towing.
August–September: number per cubic meter.

Propagation of the Stock Originating East of Mt. Desert

This region (Fig. 1) shows considerable local variation. In its western portion approaching Mt. Desert and on the Nova Scotian side of the Bay of Fundy (influenced by inflow from the outer Gulf), the spawning seasons of *Calanus* more closely approximated those to the west of Mt. Desert, while along the coast eastward from Petit Manan to St. John the seasons were progressively later. However, although evident, these local seasonal differences are relatively small, and for present biological purposes the waters east of Mt. Desert can be considered to comprise one region in which the maxima of corresponding stages of *Calanus* occur, as previously noted (p. 123), about four weeks later than in the western part of the Gulf.

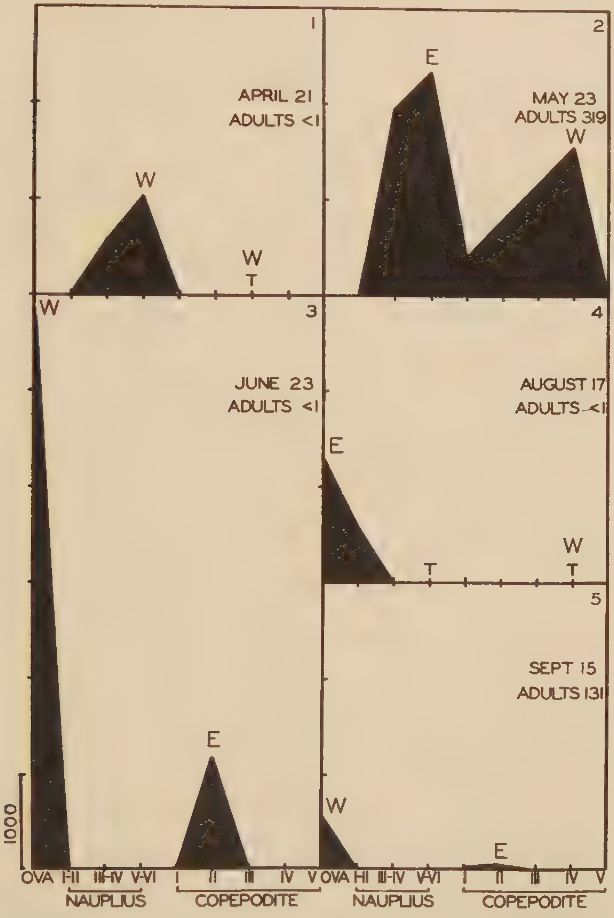

FIG. 9. Development of the western (*W*) and eastern (*E*) stocks as indicated at station 8*A* in the drift entering the Bay of Fundy in 1932.

There appear to be two less well defined propagation periods of the eastern stock, April–May and July–August. The first is indicated by eggs appearing along the New Brunswick coast on April 18 (Fig. 3) and the maximum of nauplius stages I–II in the vicinity of Petit Manan (Station 33) on April 22 (Fig. 3). Reaching nauplius V–VI a month later (May 18–24) and copepodite stages II–IV on June 20–26 (Figs. 8 and 9), it is presumed that August (8–21) eggs represent spawning by adults of this stock.

It was not possible to trace with certainty the outcome of July–August propagation because of the small number of individuals involved, but it would appear that the copepodites (stage II) entering the Bay of Fundy on September 15 (Fig. 9) were representatives of this crop. This second eastern brood of copepodites probably supplements the second and third (?) western broods to form the winter stock.

Rate of Early Development

In the Clyde Sea (Nicholls, 1933, p. 92) field and laboratory records have indicated a maximum of four weeks for the complete development of *Calanus finmarchicus*, a minimum of eleven days between the egg and first copepodite stage and intervals of three days for successive moults to stage V. A minimum of four days was required for the final moult to stage VI (adult).

Lebour (1916, p. 9), in laboratory experiments at Plymouth, found that nauplii appearing between April 17 and 24 reached copepodite stage V on May 19, having taken less than two months for development from the egg to the latter stage.

Off Möre Ruud (1929, p. 38) estimates that *Calanus finmarchicus* requires almost three months for its life cycle, allowing three to four weeks for embryonal development as indicated by Lebour (1916, p. 9). In 1926 there was about seven weeks between the maximum of nauplii and the maximum of stage VI.

In the Gulf of Maine the developmental period appears to be slightly less than in Norwegian waters, but, as observations at each station were taken at minimum intervals of one month, the rate of growth can only be approximated. In the case of the western stock, with an interval of 29–33 days between the maximum of copepodite stage III in May and the presence of eggs in June, followed by a period of 42–46 days before the next maximum of copepodite stage III, the complete cycle would appear to require from 71–79 days. Again, if eggs observed on September 15 (p. 129) can be considered to represent spawning by individuals incubating west of Mt. Desert from June 28 to July 1, and in copepodite stage III on August 11–14, then there must have been a maximum period of approximately 78–81 days between the second and third broods of eggs.

The two generations of the western stock would thus agree rather well and suggest a period of about two and one-half months from the egg to the spawning adult. Intervals between maxima of different stages also indicate about one month for the development from nauplius I to copepodite I, one-half month from copepodite I to copepodite V, and one month for the final moult, maturation, and incubation of the eggs. Although requiring confirmation by laboratory experimentation, there would seem to be about five days between moults in the nauplius stages and three days in the copepodite stages.[5]

No attempt has been made to calculate the developmental period of the eastern stock, hatching shortly before April 22 in the central area (Fig. 3, Station 33), because the greater part of this brood apparently matured and spawned in July, between cruises, and eggs taken in August no doubt represent late season spawning. This is indicated by the large percentage of nauplii up to stages III–IV in the central area on August 15.

August 15, 1932	Ova	Naup. I–II	Naup. III–IV	Naup. V–VI	Cop. I–V
Central area (Station 33)........	3,390	1,507	2,450	377	T

The rate of development would appear to be substantially the same as in the western stock, which is not surprising in view of the evidence that those members of the eastern spring brood reaching maturity probably entered the western area in early stages.

Rate of Late Development

As there was an interval of about one month between the maximum of late copepodite stages III–IV (May 27–31) and the next maximum of eggs (June 28–July 1) in the area west of Mt. Desert, it would appear that the time required for the ripening of the gonads and fertilization, after the moult to stage VI (adult), is probably about three weeks. A similar interval is suggested by the June brood if copepodite stages III–IV from the western region (August 11–13) formed the parent stock of early eggs entering the Bay of Fundy on September 15–16 (Fig. 8) in 1932. Nicholls (1933, p. 95) found that, having moulted to adults, there is a lag of from three weeks to one month before the next maximum of eggs in the Clyde Sea.

[5] At Station 8*A* copepodite stage II predominated on May 15, and copepodite stage IV on May 23, nine days later.

Data on the interval between the final moult and the time of spawning in the winter stock are available only for the Bay of Fundy. Here the period must be considerably longer than in succeeding generations in the Gulf. The winter population, almost entirely in late copepodite stages in November, is indicated in Table IV and also in a haul by Willey in Passamaquoddy Bay (1921, pp. 187–8) on November 2 in 1916 when copepodites in stage V formed 46 per cent and adult females only 2 per cent of the total macrocalanid plankton. By February 23 in 1917 adult males and females formed 47 per cent and copepodite stage V, 36 per cent. In 1932, as shown below, the winter stock in this area had almost completed moulting (97.6 per cent adults) by March 21 and a considerable proportion of the females contained developing eggs. Yet no eggs were found in these waters on April 15, and spawning had apparently just begun on May 5.

TABLE IV

Winter population of *C. finmarchicus* in Bay of Fundy. Percentages by number of various developmental stages to total zoöplankton population.

Date	Copepodite		Adult	
1931–1932	Stage IV	Stage V	♀	♂
November 16.........	3.8%	96.2%	0%	0%
March 21............	0%	2.4%	92.9	4.7

Relative Abundance of Adults

Accurate figures on the relative number of adults and individuals in developmental stages are difficult to obtain because the former cannot be sampled in a representative manner with the apparatus required for eggs and early larvæ. Copepodite stages IV and V, however, appear to have been sampled efficiently with both the coarse and fine nets, and by taking the fine net counts and applying the meter net data on the relative percentage of these stages to adults, it has been possible to obtain roughly comparable figures for the latter. Similar figures have been obtained for August and September using pump and meter net data but the error may prove to be greater in this case if it is found that late larvæ, particularly copepodite stage V, cannot be sampled representatively with the pump. There is some evidence that this might be true, in which event the mean number of both adults and late copepodite stages in the total region would be somewhat larger than indicated in Table V.

Mortality among Maturing Adults

In the Gulf of Maine during the interval between the maximum of late copepodite stages in late May and the maximum of eggs in June, there occurred the highest rate of mortality observed in zoöplankton during the year, the decline in the relative percentage of *Calanus* exceeding even the tremendous decline in the total volume of animal plankton (Fig. 2) at a time when the spring stock of this species, just reaching maturity, might have been expected to substantially increase the total plankton volume (p. 128).

A similar decline in *Calanus* in the Clyde Sea (where, as in the Gulf of Maine, the maximum of eggs coincides with the minimum of adult females) has been interpreted by Nicholls (1933, p. 95) to indicate that the period of maturation forms a very critical time during which the rate of mortality is so high that comparatively few females survive.

Support for this interpretation was found in the Bay of Fundy, where the eastern vernal crop was still in copepodite stages in late June. If the decline from May to June is not primarily due to a depletion of the food supply or unfavorable physical conditions, excessive mortality in the Bay would at this time be limited to immigrants from the west. Figure 2 shows this to be the case, as the eastern stock apparently offsets the decline of western immigrants in the Bay, and the mean volume continued to increase through June.

TABLE V

Number of *C. finmarchicus* in various stages of development, April to September, 1932.

1932	No. stations	Method	Eggs	Nauplii	Copepodites	Adults
April	27	Net	4	1615	406	128
May	26	Net	301	3013	4138	319
June	26	Net	8432	1850	307	311
August	27	Pump	2158	882	69	21
September	12	Pump	753	7	35	4

Net: number per minute. Pump: number per cubic meter.

Mortality in maturing adults of subsequent generations in the Gulf and Bay was not as clearly evident because both the meter net and pump data indicate that comparatively few survived to reach even copepodite stages. Perhaps the greater number of predatory plankton animals in summer served to keep the numbers down. Some such explanation is necessary to account for the large crop derived from the relatively small parent stock in March–April as compared with that in May–June.

Length of Life of Different Broods

The marked decline in the relative percentage of adults to copepodites following the breeding period in June (Fig. 10*A*), in view of the fact that in relation to eggs and nauplii, copepodites showed no significant increase (Fig. 10*B*), is considered to represent a dying off of adults after spawning. This appears to be a rather well-established characteristic of the species in the eastern Atlantic (Damas, 1905; Paulsen, 1906; Nicholls, 1933) and has been suggested by Bigelow (1926, p. 206) in the Gulf of Maine.

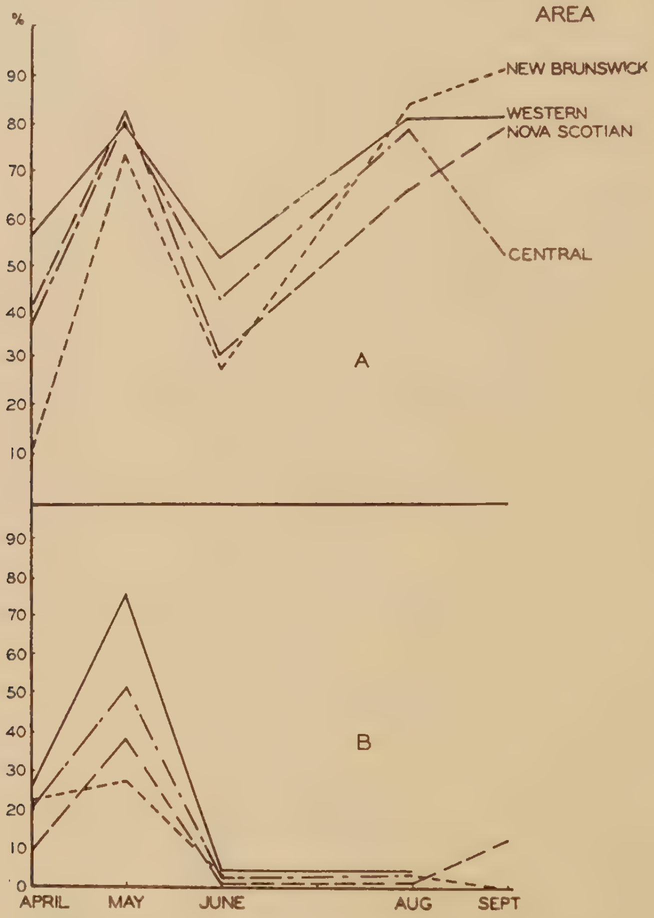

FIG. 10. *Calanus finmarchicus.* Seasonal changes in the relative percentage of (*A*) copepodites to adults, and (*B*) copepodites to eggs and nauplii.

The length of life of individuals produced in early April and maturing in June would thus probably not exceed four months, allowing two and one-half months for development to maturity and a maximum of one and one-half months of adult life (spawning adults in the western region on June 28–July 1 had greatly diminished by August 11–14 in 1932). A similar period of adult life in spring and summer (one and one-half months) has been found by Nicholls in the Clyde Sea area (1933, p. 92).

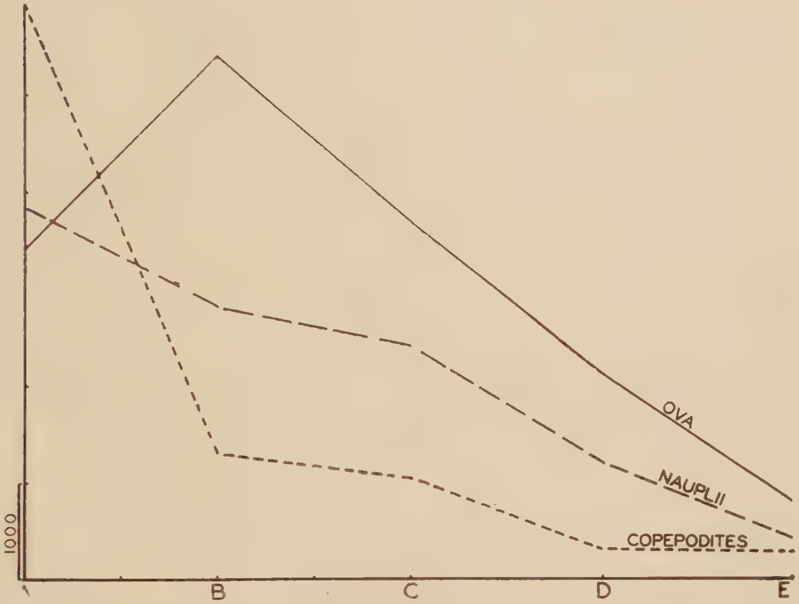

FIG. 11. Mean numbers of ova, nauplius and copepodite stages per minute of hauling for the period April–July, 1932.

Sections: *A*. Casco Bay, *B*. Penobscot Bay, *C*. Mt. Desert,
D. Moose Peak, *E*. Cape Spencer.

In regard to the winter stock, in cold areas with fewer generations the length of life must be longer than in regions such as the Clyde Sea where spawning begins very early in the year. Our data would indicate that the increase in the number of copepodites in September, observed by Bigelow (1926, p. 207) in the Gulf and in 1932 in the drift entering the Bay of Fundy (increased from 0.3 per cent to 13.6 per cent, Fig. 10*B*), represented arrested development of at least a part of the June crop from the western region, supplemented perhaps to some extent by the July-August crop from the waters east of Mt. Desert. The small numbers of eggs of the third western brood in September do not appear adequate to account for the winter population. If the winter group then consists largely of individuals produced in June–August and dying off after spawning the following March–April, a maximum existence of approximately 10–11 months is indicated. September-spawned *Calanus* would have a maximum existence of 7–8 months. In the Bay of Fundy the period must be even longer (p. 133). Nicholls estimates (1933, pp. 91–92) the length of life of *Calanus* in the Clyde Sea area to be about nine weeks after the winter group has moulted to stage VI, with a total existence of 7–8 months.

There is some evidence that after reaching maturity the males of *Calanus finmarchicus* die off some time before the females. Referring again to Willey's records from the Quoddy region (1921, p. 187), of the adults taken on February 23 in 1917, males formed 20 per cent and females 27 per cent. In 1932 on March 21, a month later, females formed 92.9 per cent of the *Calanus* stock and males 4.7 per cent. Damas (1905) also found males of this species rare except at the epoch of vernal reproduction.

TABLE VI

Number of *C. finmarchicus* found in different stages in the New Brunswick area, April to September. April–June, number per minute. July to September, number per cubic meter.

New Brunswick area	Station	Ova	Nauplius			Copepodite				
1932			I–II	III–IV	V–VI	I	II	III	IV	V
April 15	5									
May 4	5	17								
May 19	5			31	62					
June 20	5	7608		507	507				T	
July 30	5	710	140							
August 21	5	375	187							
September 16	11A		40							

Relative Importance of Different Spawning Areas

The contention of previous observers (Willey, 1921, p. 189; Bigelow 1926, p. 207) that the western Gulf probably forms the principal source of supply of *Calanus* for the entire region, is borne out by the present investigations. At all times the coastal region west of Mt. Desert yielded the greatest numbers of eggs, larvæ, and adults, and the rapid decline to the eastward (Fig. 11), combined with the distribution of larvæ, designate it as the probable source of the major part of the population in the outer Gulf, the central area, and the Bay of Fundy. The fluctuations in the mean volume and relative percentage of *Calanus* in the total region in 1932 paralleled the seasonal changes in the western area (Fig. 2).

No doubt a portion of the individuals produced in the eastern region, particularly near its western margin, survive because the stock in very small numbers can be traced through successive generations. However, over the greater part of the Bay of Fundy and the turbulent coastal region of the Gulf east of Petit Manan, there is no evidence of any successful production of *Calanus*, although eggs transported west from the latter area may complete their development in a more favorable environment.

In the Quoddy region (Station 5), somewhat removed from the path of the drift from the Gulf, hauls throughout the season consisted principally of eggs with relatively few nauplii. Copepodite stages were taken during the summer with a meter net but their numbers were so small that almost none were found in pump and fine net samples. The large brood produced by immigrant adults in late June had apparently entirely vanished a month later, and eggs of the eastern stock in late July and August seem to have disappeared by September 16. A similar condition was found in August and September, 1931.

SUMMARY

1. *Calanus finmarchicus* is the most abundant pelagic animal in the Gulf of Maine, averaging 39.9 per cent of the total zoöplankton population during the period April to September, 1932, with a peak of 60.4 per cent in May. In the Bay of Fundy there was a mean of 35.5 per cent for the year 1931–32.

2. The adult stock varies markedly in abundance in different areas, the smallest numbers occurring in the Bay of Fundy and westward along the coast of Maine to Penobscot Bay. The population is everywhere at a minimum in late February and early March.

3. *Calanus* passes the winter largely in copepodite stage V, the final moult taking place in February and early March shortly before vernal augmentation.

4. An average difference of approximately one month in the time of spawning in the eastern and western parts of the region is reflected in succeeding generations after dispersal. Two breeding stocks can thus be distinguished.

5. In the western stock there are two well-defined breeding periods, March–April, and June–July, with a possible third in September, and two periods, April–May, and July–August in the eastern stock.

6. A developmental period of two and one-half months is indicated in both stocks, one month from nauplius I to copepodite I, one-half month from copepodite I to copepodite V, and one month for the final moult, maturation, and incubation of eggs.

7. Mortality is highest among maturing adults.

8. The total length of life in spring and summer does not exceed four months. The winter stock has a maximum existence of 10–11 months.

9. After reaching maturity the males die off before the females.

10. The western Gulf forms the principal source of supply of *Calanus* for the entire region. Propagation east of Mt. Desert in the inner Gulf is largely if not entirely, unsuccessful.

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Determination of Iron in Sea Water

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CONSIDERABLE interest attaches to the heavy metals present in small amounts in sea water. Of these, iron is particularly important, for there is little doubt but that it may be a limiting factor in the growth of certain organisms. Thompson, Bremner, and Jamieson (*3*) reviewed the literature on this subject and proposed a method for the determination of total iron in the water.

Any study of the availability of iron must involve its separation into the several possible forms of combination. Thompson and Bremner later (*1*) modified their method and determined both "soluble" and "total" iron in a number of samples of water. The present paper describes an attempt to determine the concentration of "free dissolved ferrous and ferric ions," and since a somewhat different method of analysis is used the results are not strictly comparable with those of Thompson and Bremner, who evaporated filtered samples with sulfuric acid to eliminate interfering substances such as fluoride and organic matter, and then determined iron colorimetrically with thiocyanate, extracting the color with isoamyl alcohol.

The method here described depends primarily upon the precipitation of iron as sulfide. The results therefore include iron in all forms of combination yielding ferrous ions in the concentrations demanded by the solubility product of ferrous sulfide. Ferric ions are also included, owing to the reducing action of the sulfide ion in the concentrations used. Admittedly, organic matter interferes with the precipitation, but whether this actually occurs in sea water and, if so, how much of the iron is held in such organic combination, is outside the present discussion.

Much of the early work on heavy metals in sea water was based upon their precipitation by sulfide, but unless some method of concentration is used the removal is incomplete in such high dilutions. However, the fortunate presence of magnesium in relatively large amounts makes it possible to use a process of co-precipitation, the extremely small quantities of ferrous sulfide resulting from the addition of alkaline sulfide being carried down quantitatively by the larger amount of basic magnesium salts simultaneously formed. The iron is brought into solution again in small volume, oxidized, and finally estimated colorimetrically with thiocyanate.

A serious difficulty with this latter reaction has always been the instability of the colored compound in water solution. While trying various methods of extraction it was observed that ethylene glycol monobutyl ether, which is a moderately good extractive, will, when dissolved in the solution in small amounts, stabilize the color reaction and retard the fading long enough to permit colorimetric comparison in the water solution without extraction by any organic solvent.

Method Used

A 500-ml. sample of sea water is filtered through a Seitz filter and transferred to a 1-liter Erlenmeyer flask. Five milliliters of ammonium sulfide reagent are added and the solution is brought to boiling for a few moments. A fine magnesium precipitate should form, which settles quickly on standing. If the precipitate fails to appear, the solution is not sufficiently alkaline, and a small amount of ammonium hydroxide (ordinarily not more than 5 ml.) should be added and the boiling repeated. The precipitate is filtered on a small paper filter in a Gooch crucible, under gentle suction. After washing, it is dissolved in 20 ml. of dilute hydrochloric acid (approximately $2.5N$) and the solution boiled to remove hydrogen sulfide. Then 2 ml. of bromine water are added and the excess bromine is boiled off. When the solution has cooled, 5 ml. of concentrated hydrochloric acid are added, and the solution is made alkaline with concentrated ammonium hydroxide. In this way iron is precipitated, with only small traces of magnesium. The precipitate is filtered off on a small Whatman paper (No. 42) and dissolved by running 20 ml. of $2.5N$ hydrochloric acid through the filter. The filtrate is caught in a 100-ml. Nessler tube and made up to the mark. Then 2 ml. of ethylene glycol monobutyl ether and 10 ml. of a 10 per cent solution of potassium thiocyanate are added and the contents of the tube mixed by covering the ground end of the tube with a glass plate and inverting. The color is compared with a set of standards in similar tubes. These are prepared by adding 5 ml. of concentrated hydrochloric acid and the desired amount of standard iron solution (0.002, 0.005, 0.01, 0.015, 0.02 mg. of iron as ferric alum) to Nessler tubes and treating with potassium thiocyanate and the ether as before. The colors will remain permanent for an hour or more.

If preferred, the color comparison may be carried out in a long-tube colorimeter, which makes closer differentiation possible than with the use of Nessler tubes, but it is very doubtful whether in the long run the results are any more accurate.

Occasionally samples of c. p. hydrochloric acid and ammonium hydroxide are found which are practically iron-free. If not, the reagents may be made by redistilling the purified gases into pure water. The ammonium sulfide reagent is made by running hydrogen sulfide into iron-free ammonium hydroxide through a purification train consisting of a wash-bottle and a 120-cm. (4-ft.) tube packed with glass wool.

The bromine water was tested daily for the presence of iron taken from the glass. The greatest source of error was found in the filter paper. This was minimized by soaking all filter paper and pads in 1 to 1 hydrochloric acid and washing carefully.

Blanks. In the early stages of the work, before reagents were adequately purified, blank values from 0.005 to 0.0065 mg. were found. Later this was consistently lowered to 0.002 to 0.004 mg. Each reagent was separately tested as a possible source of iron, with the following results, when reduced to the basis of a single determination:

	Mg.
Bromine	0.0008
$(NH_4)_2S$	0.0010
HCl	0.0026
NH_4OH	0.0010
Total	0.0054

Duplicate Determinations. The following pairs of results were obtained at various times from duplicate samples, independently precipitated and treated:

Mg. of Iron Found							
0.012	0.005	0.018	0.017	0.015	0.023	0.005	0.015
0.010	0.004	0.017	0.019	0.015	0.021	0.004	0.015

0.0044	0.0077	0.0052	(comparison made in colorimeter)
0.0045	0.0073	0.0053	

Recovery of Added Iron

The test of the adequacy of the method is in the completeness with which added quantities of iron may be recovered. Known amounts of iron, in the order of magnitude which might be expected to be present in the original water, were added to sea-water samples with the results shown in Table I. The iron added was in the form of ferric ammonium sulfate. It is evident from the completeness of the recovery that ferric iron is completely reduced to ferrous by the sulfide ion, before precipitation of ferrous sulfide.

Filtration

Obviously, if the original water is not filtered to remove suspended matter results will be high, owing to iron contained in such material, even though the subsequent treatment is not vigorous enough to oxidize or decompose completely the organic iron compounds contained in diatoms, etc. This is borne out by the results shown from Station 1731, the samples from which were not filtered, and which are higher than any others. The results given in Table II, comparing duplicate samples, one of which had been filtered through No. 42 filter paper and the other through a Seitz filter, indicate that water treated in the latter way is more completely free from iron-bearing suspended matter. The samples in which Thompson and Bremner (*1*) determined "soluble iron" were filtered through No. 42 paper, which may account for their slightly higher results.

TABLE I. RECOVERY OF ADDED IRON

Before Adding Iron *Mg.*	Iron Added *Mg.*	Found after Adding Iron *Mg.*	Iron Recovered *Mg.*	
0.01	0.02	0.025	0.015	
0.01	0.03	0.04	0.03	
0.015	0.02	0.04	0.025	
0.015	0.02	0.035	0.02	
0.012	0.03	0.042	0.03	
0.01	0.02	0.035	0.015	
0.001	0.005	0.0062	0.0052	Comparison in colorimeter
0.002	0.005	0.0068	0.0048	
0.015	0.010	0.025	0.010	High blank (0.007 mg.) Reagents and paper impure
0.017	0.010	0.025	0.008	
0.010	0.010	0.023	0.013	
0.012	0.010	0.023	0.011	
0.010	0.010	0.021	0.011	
0.005	0.010	0.015	0.010	
0.004	0.010	0.015	0.011	
0.007	0.010	0.015	0.008	
0.005	0.010	0.017	0.012	
0.008	0.010	0.017	0.009	
0.008	0.010	0.018	0.010	
0.005	0.010	0.015	0.010	
0.004	0.010	0.015	0.011	

TABLE II. DUPLICATE SAMPLES FILTERED IN DIFFERENT WAYS

(Mg. of iron found)

No. 42 paper	0.0045	0.017	0.025	0.017	
Seitz filter	0.002	0.010	0.023	0.010	
No. 42 paper	0.004	0.003	0.0009	0.0004	Comparison in colorimeter
Seitz filter	0.0003	0.0003	0.0004	0.0000	

TABLE III. INFLUENCE OF FLUORIDE

Fe in Original Water *Mg.*	Fluoride Added to Sample *Mg.*	Iron Found *Mg.*
0.018	0.25	0.017
0.017	0.25	0.019
0.012	0.25	0.010
0.012	0.50	0.011
0.012	0.75	0.013
0.016	0.12	0.015
0.016	0.50	0.021
0.016	1.00	0.015

TABLE IV. IRON IN SEA WATER

Location	Depth *M.*	Temperature ° *C.*	Salinity 0/00	Iron *Mg./cu. m.*
Station 1731	0	28.20	36.02	19 Not
38° 06′ N., 68° 54′ W.	50	26.81	36.00	41 filtered
	100	23.42	36.40	30 Compare
	150	20.95	36.58	16 with following
	200	18.65	36.42	16 lowing
	860	4.71	34.96	15 stations
	1685	3.48	34.94	8 Filtered
Station 1732	0	27.67	35.90	13
37° 21′ N., 68° 31′ W.	1370	4.65	34.96	4
	2390	3.42	34.96	6
	2830	3.11	34.97	10
	3830	2.50	34.87	8
Station 1734	0	25.64	36.00	9
36° 27′ N., 68° 38′ W.	50	21.03		2
	87	19.75	36.56	3
	175	18.55	36.51	5
	365	17.96	35.53	5
	550	17.00	36.35	6
	730	14.43	35.90	1
	900	10.21	35.34	4
	1330	4.82	34.96	8
	1550	4.08	34.97	2
	2440	3.45	34.96	2
Station 2450	0	22.23	33.15	10
39° 37′ N., 69° 57′ W.	50	9.35	34.39	4
	500	5.08	34.96	6
	1000	3.88	34.96	14
	2200	3.29	34.96	8
Station 2458	0	27.8	36.26	6
35° 54′ N., 67° 47′ W.	100	22.84	36.47	6
	200	18.93	36.56	6
	500	17.97	36.49	12
	1000	10.2	35.25	14
	2500	3.37	34.90	8
Station 2220	0	13.96	31.73	6
42° 17′ N., 69° 36′ W.	20	13.88	31.95	0
(Gulf of Maine)	40	4.09	32.64	0
	60	3.66	32.79	0
	80	3.65	32.92	4
	120	3.98	33.25	4
	175	6.07	33.96	18 (?)
	200	6.48	34.12	0
Station 2224	0	12.68	32.00	0
43° 12′ N., 69° 18′ W.	40	5.57	32.60	0
(Gulf of Maine)	80	4.15	32.80	0
	175	3.94	33.22	0
Station 2227	0	12.56	32.28	4
42° 15′ N., 67° 16′ W.	40	5.01	32.82	0
(Gulf of Maine)	80	4.78	33.12	0
	175	5.39	33.80	0
Station 2228	0	9.63	32.52	0
41° 57′ N., 67° 06′ W.	30	9.59	32.52	0
(Gulf of Maine)	50	9.61	32.52	0
Surface Samples near Woods Hole				
Woods Hole Harbor (8/6/34)				6
(8/8/34)				8
(8/28/34)				7
(8/28/35)				3
Woods Hole Eel Pond				0
Mouth of Great Pond				4
Head of Waquoit Bay				10
Tarpaulin Cove				6
Buzzards Bay, K–1				3
Buzzards Bay, K–2				0
Vineyard Sound, L–1				0
Vineyard Sound, L–2				0

The varying results following different methods of filtration are evidently due not to iron dissolved from the filter material, but rather to the varying efficiency of different filtration technics in the removal of very fine suspended matter, bacteria, or other microörganisms containing iron. The greater portion of the total iron of the water is in suspension.

Influence of Fluoride

Thompson, Bremner, and Jamieson mention the possible occurrence of iron in the form of a ferrifluoride complex, which inactivates the iron as far as the thiocyanate reaction is concerned. Although this may be true, the presence of fluoride has no influence on the determination and recovery of iron by the present method. The amount of fluoride in the water should be sufficient to form such complex ions with much more than the iron already present; nevertheless, added iron is recovered quantitatively. Furthermore, fluoride was added to water samples containing small amounts of iron, which were precipitated and determined both before and after the addition of fluoride. The results shown in Table III establish the fact that fluoride in several times the normal concentration has no influence on the determination of iron by this method.

Iron in Sea Water

Sea-water samples from a number of places within cruising distance of Woods Hole were analyzed by the above procedure. The results in Table IV show that there is a small but significant amount of free inorganic iron—i. e., iron precipitable as sulfide—generally present in the water. The concentration is seldom more than 10 mg. per cubic meter, or ten parts per billion. This is about one-quarter to one-twentieth of the amount of total iron found in the waters of the Puget Sound area, by the authors mentioned.

The figures of Thompson and Bremner (*2*) for "soluble iron" are also somewhat higher than those shown here, except in the case of their one deep, off-shore station, where results were much the same as at Stations 1732 and 1734. Their discovery of a maximum iron concentration at 1000 to 1200 meters seems to have its counterpart here, too, at Stations 2450, 2458, and possibly 1734, although at the first of these, at least, it does not coincide with the depth of minimum oxygen concentration, which the above authors think is related to it.

The water is occasionally free of this form of iron, especially on the surface near the shore, and sometimes at other depths, as at Stations 2220–28 in the Gulf of Maine. Whether this is entirely due to utilization of the metal biologically, or whether this same process is the cause of the vertical differences in concentration (as was shown to be the case with total iron, *3*), cannot be decided conclusively from the present data. At any rate, the growth of diatoms would seem to depend principally upon other forms of iron than those responding to this method of analysis. Presumably these are in the nature of organic or nondissociable compounds.

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(1) Thompson and Bremner, *J. conseil intern. exploration mer*, **10**, 33 (1935).
(2) *Ibid.*, p. 39.
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Contribution No. 88

Mixing and Residual Currents in Tidal Waters as Illustrated in the Bay of Fundy

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ABSTRACT

(1) The Saint John estuarial water flows out to sea as a strongly stratified layer, about 10 metres thick, retaining its lower boundary as far as Grand Manan island, a distance of 74 km. Persistence is due to the high density gradient combined with the low velocity gradient through the layer as it flows out over the deep homogeneous water. (2) The homogeneity produced in shoal water by tidal stirring excludes permanent residual currents if sufficient light water is available, the outward gravity force balancing the inward dynamic force of the peripheral current. (3) Where the waters of the bay shoal gradually the turbulent influence of bottom friction extends upward 20 to 50 metres, causing the isosteric surfaces to bend downward as they come within this distance from the bottom, but for a steep rise of the bottom the isosteres continue horizontally to meet it. (4) There are found in juxtaposition (*a*) stratified regions where tidal mixing causes an outflow of mixed water at an intermediate depth with an inflow both at surface and bottom, and (*b*) regions where a local supply of fresh water is mixed with salter water and flows away at the surface, with a compensating inflow at bottom only. (5) Calculation shows that of the total mixing in the bay of Fundy that is effective in producing a circulation, 3% occurs in the Saint John estuary, 6% in the Quoddy passages and 14% at the head of the bay.

PREFACE

The following paper on the physical oceanography of the bay of Fundy is one of a group of four, published by the investigators of the International Passamaquoddy Fisheries Commission. The subjects and authors of the other papers are: the phytoplankton by Dr. H. H. Gran and Mr. Trygve Braarud (1935), the zooplankton by Dr. Charles J. Fish and Dr. Martin Johnson (unpub.), and the herring by Mr. Michael Graham (1936).

All the titrations and many of the original observations were ably carried out by Mr. Charles J. Hughes at St. Andrews, N.B. During the winter of 1932-33 leave of absence from Queen's University was kindly granted to the writer and the work of reducing the observations was carried on at Woods Hole. The preparation of the paper has taken considerable time and has been made possible chiefly through the assistance and facilities offered by the Woods Hole Oceanographic Institution. To Dr. H. B. Bigelow and to other members of the Institu-

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tion, as well as to Dr. A. G. Huntsman and the investigators of the Commission, I am indebted for many profitable suggestions. It is also a pleasure to thank Mr. K. G. Chisholm of the Water Power and Hydrometric Bureau at Halifax for information on drainage, and Mr. Dexter P. Cooper for the use of blueprints of the Quoddy Project.

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PART I. GENERAL INTRODUCTION

1. History and Equipment

The bay of Fundy is well known for its extreme tidal range. To the oceanographer it presents a problem in which turbulence phenomena are of paramount importance. Our knowledge of oceanic turbulence is so limited that the water movements in this bay cannot be derived satisfactorily from the usual hydrographic observations. In many parts the balance between static and dynamic forces is too delicate to admit of simple solution by analyses based on occasional observations. The obvious dominant movement is that of the tidal oscillation, but in addition there is an equally important progressive movement which on the surface consists of a counter-clockwise circulation around the bay. Considerable knowledge of this circulation has been gained by the Biological Board of Canada from its station at St. Andrews, N.B., but unfortunately much of the information collected has never been published. A few papers by A. G. Huntsman and two by J. W. Mavor (1922, 1923) in addition to the publications of W. Bell Dawson and the Canadian Hydrographic Service furnish nearly all of the available knowledge of the physical oceanography of the bay of Fundy.

The data and results presented in this paper were obtained as the hydrographic part of the investigations of the International Passamaquoddy Fisheries Commission. The object of this Commission was to determine the probable effect on the fisheries of the construction and operation of the Cooper Quoddy Project, a proposed tidal power project involving the damming of Passamaquoddy and Cobscook bays. Hence the hydrographical part of the investigation was concerned primarily with determining the part now played by the Passamaquoddy mixing mechanism and with estimating the changes which might be brought about by the construction of the dams. The period of the investigation covered the summers of 1931 and 1932, but as all the data from the first year were destroyed by fire the observations presented cover a single year only. Since the boats used were shared by the plankton investigators they were not always available for hydrographic work and the program of each investigator had to be suited to the needs of others. On the other hand the contemporary study of the plankton and hydrography was of mutual advantage.

The two boats used in the hydrographical work were the U.S. Bureau of Fisheries' "Pelican" and the Biological Board of Canada's "Prince". Neither boat was large enough to stand bad weather in the open sea and the "Prince" was in a condition suitable only for use near shore. Samples were collected by means of Knudsen water-bottles and titrated in the laboratory by the standard Mohr method. Temperatures were measured by Schmidt or Richter and Weiss thermometers calibrated in tenths of a degree and read by means of a lens mounted in a holder, hundredths of a degree being estimated. In general two thermometers were used on each bottle. When possible both boats were used so that simultaneous observations could be made along two sections. When only one boat was at work successive sections were made on the same phase of the tide, usually at low water. For longer sections, occupying all or the greater part of a tidal period, there was of course no object in doing this.

2. TOPOGRAPHY

The bay of Fundy extends in a north-easterly direction from the gulf of Maine, and lies between the Canadian provinces of New Brunswick and Nova Scotia. Excluding the funnel-shaped mouth of the bay, its length is about 120 miles (220 km.) and its average width about 30 miles (56 km.).* As can be seen from the bathymetric chart in figure 1, the depth increases fairly uniformly towards the gulf of Maine. The deepest channel connecting the bay to the gulf is about 150 metres deep, while within the bay there is an area of about 460 square (statute) miles (ca. 1600 sq. km.) whose depth is between 150 and 200 metres. Between the western edge of this deep basin and Grand Manan island there is a region of ledges, shoals and rocks, where heavy tidal rips are found, particularly on the ebb. The most important of the marginal features are the two arms at the head of the bay where the tide reaches its maximum range, the Saint John river with its large contribution of fresh water, and Passamaquoddy bay with its intense tidal mixing.

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*All distances at sea are measured in nautical miles. 1 sea mile = 1.15 land miles = 1.85 kilometres.

A good description of the geology of the region has been given by Johnson (1925). The most striking features of the coast line are the rectilinear shorelines of the south-eastern side of the bay and of Grand Manan channel, contrasted with the irregular drowned valley type of shore on the northeastern side below Saint John. It is important from the oceanographic viewpoint to know that these straight shorelines are not headlands which have been cut back under wave attack and which are now in the mature stage of shoreline evolution. According to Johnson the bay of Fundy is a broad Triassic lowland well worn down and deeply submerged. The southeastern coast is the projecting edge of a prominent lava sheet, forming a trap ridge, while Annapolis basin and St. Mary bay belong to a submerged valley eroded on the strip of weak sandstones exposed between the lava sheet and the nearby crystallines. On the New Brunswick side the bold shore from Quaco to Salisbury bay and its continuation from West Quoddy head to Machias bay represents a fault-line scarp now much

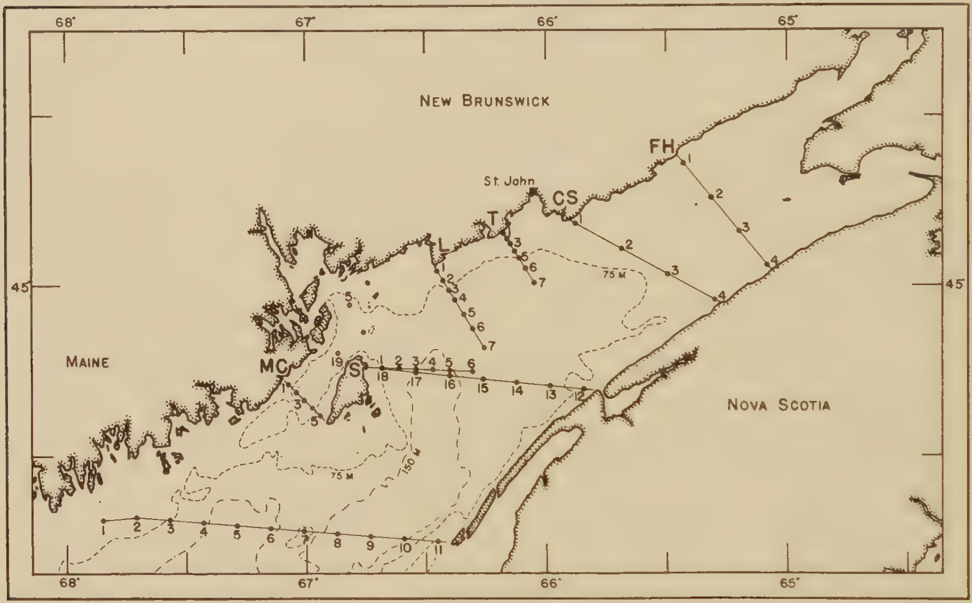

Figure 1. Bay of Fundy. Bathymetric chart and key to stations.

worn by erosion, against which the sea came to rest after the submergence of the Acadian Triassic Lowland.

Mavor (1922) gives a detailed description of the physical features of the bay, including a sketch of the bottom deposits as given on the charts of the region. The distribution of mud is interesting, for after being brought to the sea by the rivers its precipitation is sufficiently slow for it to indicate the general trend of the currents in the vicinity of the point of entry. It is well known (Gibson 1933, page 259) that a suspension of mud in fresh water will be precipitated on mixing with sea water. The settlement of the heavier or larger particles may be little affected by a saline solution, but the clearing of the solution is accelerated by the coagulation of the finer particles. From experiments it appears that a silt mixture will precipitate and clear about seven times as quickly in sea water as in fresh water. If there is strong tidal turbulence, however, the settling will not take place until a region is reached where the waters are relatively quiet. Thus the presence of mud on the bottom denotes the passage of water from the rivers, together with an absence of any great turbulence. For example, the occurrence of mud from the mouth of the Saint John river to the Quoddy region, with a narrow branch stretching down the east side of Grand Manan island, is good evidence of the general counter-clockwise circulation, but the absence of mud in Grand Manan channel is due to the strong currents there and does not in itself prove that all the Saint John water passes to the east of Grand Manan. It is necessary to complete this discussion on the distribution of mud by giving Johnson's explanation of the formation of the extensive silt deposits in the reclaimed marshland at the head of the bay of Fundy.

> "The source of the silts . . . is to be found in the relatively weak red sandstones and shales which border and presumably underlie the Fundy lowland. . . . As the sea worked over this material, part of it was doubtless carried out to deep water, but a large part was always shifted towards the head of the embayment by tidal currents, and there deposited during slack water. Continued subsidence caused the sea to rework and shift northward the tidal deposits as well as the subaerial deposits with the result that we find at the present head of the Bay of Fundy material from the entire lowland repeatedly shifted northward from successive heads of the Bay as the land sank."

It is clear from this that tidal scouring keeps the bottom clean except for regions where the deposition of silt is going on at present, presumably from the river outflow. The turbidity and sharply marked boundary of the Saint John outflow are commonly observed. On July 12, 1932, when the outflow was relatively small, Secchi disc readings taken by Graham gave a visibility depth of only 4 metres at a point 9 miles (16.7 km.) SSW of St. John, whereas at a point 15 miles (28 km.) SXE from Saint John, the depth was 12 metres. These two readings, though taken only 10 miles (18 km.) apart were respectively the lowest and highest which he obtained within the coastal waters of the bay. Since the origin of the mud on the bottom of the bay is recent it seems valid to use it as evidence of the path taken by the river water.

3. WATERSHED

Through the kindness of Mr. K. G. Chisholm, District Hydraulic Engineer, considerable hydrometric data has been made available for studying the fresh water drainage into the bay of Fundy. Figure 3 gives a table of the average monthly discharge from each of the seven drainage areas tributary to the bay of Fundy, as well as the total discharge into the bay for each month. The watershed for the bay of Fundy is 31,500 square miles (81,600 sq. km.), while for the whole gulf of Maine it is only about twice that area. Thus a great part of the fresh water contributed to the gulf of Maine comes to it from the bay of Fundy. In February and March the fresh water flowing into the bay is small and there is little difference in salinity between the bay of Fundy and the neighbouring part of the gulf of Maine. But in the early spring the snow and ice begin to melt, the rivers become swollen, and there is a great discharge of fresh water known as the spring freshets. The time of occurrence and the duration

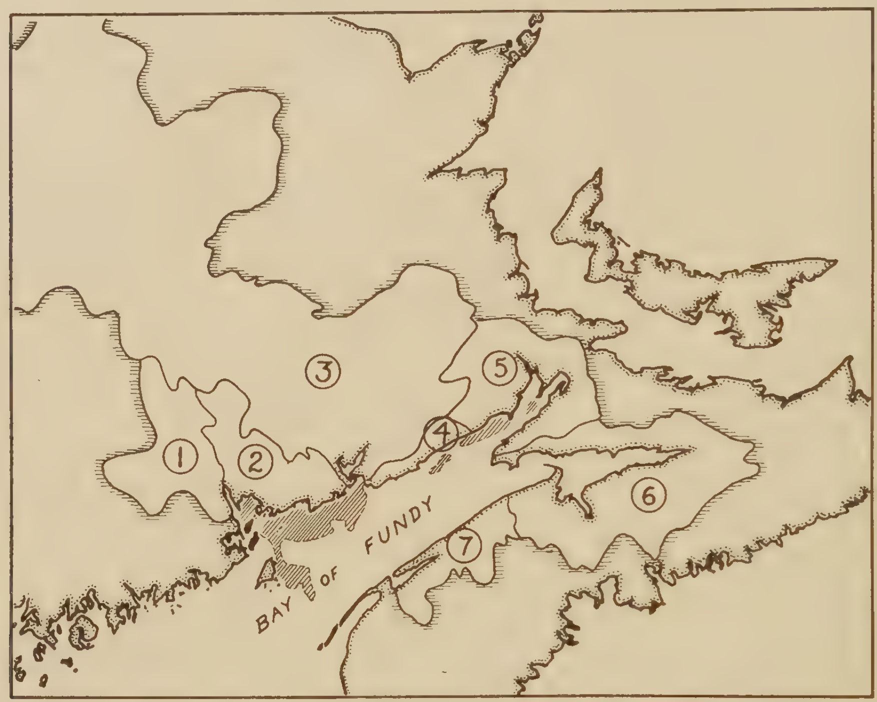

FIGURE 2. Drainage areas (numbered) and mud deposits in the bay (diagonal hatching).

AVERAGE RATES OF DISCHARGE IN CU.FT./SEC. OF THE REGIONS TRIBUTARY TO THE BAY OF FUNDY

REGION	AREA	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	YEAR
1. ST.CROIX	1,500	1,965	2,040	1,965	1,860	1,710	2,565	4,965	4,065	2,130	1,830	1,755	1,695	2,325
2. MAGAGUADAVIC	1,050	1,911	2,320	2,089	1,375	850	2,373	6,930	3,675	1,606	1,102	672	703	2,089
3. ST.JOHN	21,500	24,500	37,620	20,420	13,330	8,600	13,970	77,200	110,700	39,550	21,280	14,840	14,620	33,100
4. NORTH SHORE	960	2,342	2,563	2,630	2,276	1,181	3,110	6,807	3,264	1,335	1,104	1,075	1,095	2,295
5. CHIGNECTO BAY	2,160	4,600	3,844	4,493	5,573	3,391	5,465	14,770	9,500	2,721	1,642	1,642	1,534	4,795
6. MINAS BASIN	3,300	6,400	8,183	11,290	11,420	6,830	11,920	20,730	11,720	4,422	3,696	3,267	3,433	8,448
7. SOUTH SHORE	986	1,519	2,210	3,313	3,796	2,485	4,073	4,674	2,407	1,065	878	838	927	2,348
TOTAL INTO BAY OF FUNDY	31,456	43,237	58,780	46,200	39,630	25,047	43,476	136,076	145,331	52,829	31,532	24,089	24,007	55,400

FIGURE 3. Table of average rates of discharge for each drainage area.

of these freshets vary from year to year and from one river to another, but they usually occur in April and May. At this time the Saint John river alone has an average outflow of about 94,000 cu. ft. (ca. 2700 cu. m.) per sec. To illustrate the amount of fresh water contributed, consider the region of the bay north of a line joining W. Quoddy head to Digby gut, an area of about 4330 sq. (statute) miles (11,200 sq. km.). If all the fresh water flowing into this area during April and May were to accumulate it would form a layer over 6 feet (1.8 m.) deep. Of course this water is not all retained in the bay or accumulated on the surface, for it is dissipated both by vertical mixing and by outflow to the gulf of Maine. But both these processes are slow, and not only does the bay of Fundy remain fresher than the gulf of Maine throughout the summer but also the whole character of the water movements is affected by the presence of this fresh surface layer. (See part II, sects. 4 and 5). In certain restricted regions of the bay of Fundy the concentration of freshet water is even greater than that quoted for the major part of the bay. For example, in the single month of April, 1932, the discharge of freshet water into Passamaquoddy bay was equivalent to a layer nearly 14 feet (4.3 m.) deep over its area of 100 sq. (statute) miles (260 sq. km.). The variation of the time of occurrence of the maximum freshets is shown in figure 4 in which the monthly discharge of the Saint John river, measured at Pokiok, N.B., is plotted for the years 1922, 1930, 1932. The year 1922 must have had a very late spring, for instead of the usual freshets in April and May the discharge in April was less than usual, in May very much less, and in June, when the freshets are usually over, the maximum monthly discharge occurred. 1930 and 1932 are typical years showing maxima in May and April respectively. The freshets from the shorter rivers naturally tend to be earlier than those from the Saint John, but the latter may safely be taken as an index for the whole region. Figure 5 shows the monthly discharge into Passamaquoddy bay during 1932 and also the mean monthly discharge for a number of years. The variation of the discharge in the Saint John river from one time to another is best illustrated by the graphs in figure 6, which show the daily discharge during the freshet month of April and also during the summer month of July. The rate of dispersal of this fresh water on entering the bay will depend on the tidal conditions at the time, as well as on the winds, so that the resulting distribution of salinity and temperature at a certain time of the year may differ considerably from one year to another, and even the change from day to day may be quite rapid.

4. Tidal Effects

General information on the tides may be found in the publications of Dawson (1920) and Marmer (1926, 1928, 1932). The tides in bays are of two types: the progressive wave, with high water progressively later and the range decreasing from mouth to head; and the stationary wave in which there is little or no difference in the time of high water throughout the bay, and the range increases from mouth to head. For the stationary type to occur it is necessary that the dimensions of the bay shall be such that the natural period of oscillation of the water shall be very nearly equal to the period of the tidal movement outside the

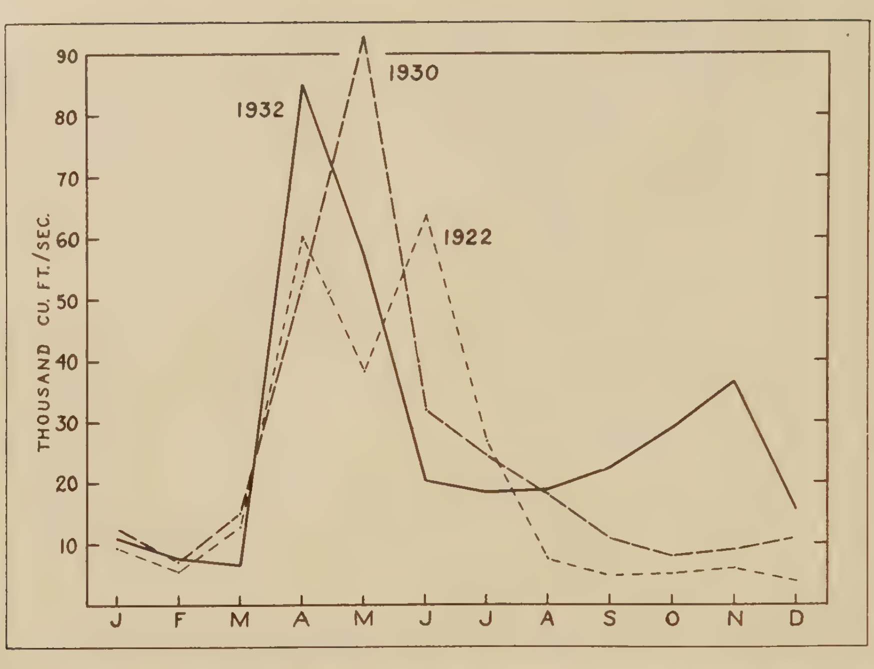

FIGURE 4. Monthly discharge of Saint John river, showing variations in the time of spring freshets.

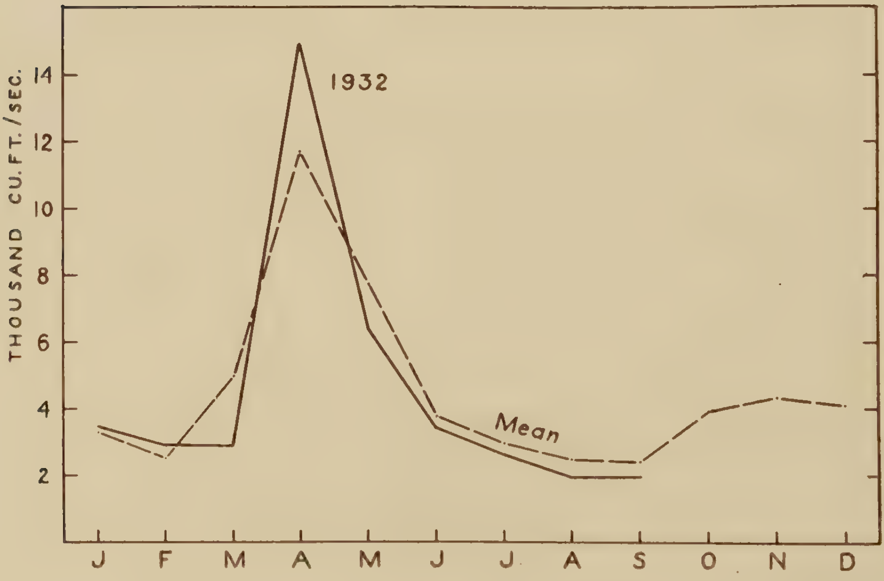

FIGURE 5. Monthly discharge into Passamaquoddy bay.

bay. This is the case in the bay of Fundy where the natural period of oscillation is about 12 hours. There is only 6 minutes difference in the time of high water from Machias Seal island to Isle Haute, 100 miles (185 km.) apart, yet the tidal range is doubled. Another important feature of the stationary wave tide is that slack water occurs at or near high and low water, and the current is strongest at half flood and half ebb. This has an important bearing on the comparative range of the tide on opposite sides of the bay. When the tidal wave is progressive the range on one shore is greater than on the other, but if slack water occurs at high and low water, as with a standing wave, there can be no effect of the earth's rotation at these times and the range will be the same at opposite points on either shore. In the bay of Fundy the range on the southern shore is only slightly greater than on the northern, so that the tide is undoubtedly of the standing wave type.

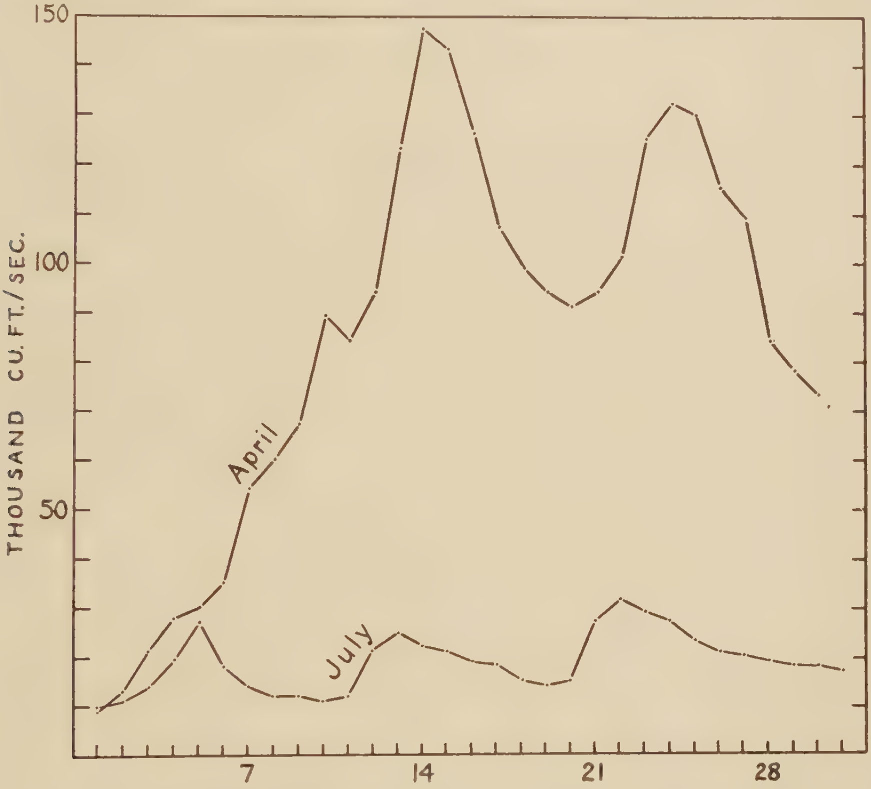

FIGURE 6. Daily discharge of Saint John river at Pokiok, N.B., for April and July, 1932.

According to Dawson's tidal current measurements in the bay "the current is as strong down to a depth of 30 fathoms as it is on the surface, and at most places it turns in direction on the surface and below at practically the same time." This means that the currents are quite strong near the bottom and the irregularities of the bottom generate eddies which break down the natural stratification for a considerable height above the bottom. In the upper part of the bay this turbulence reaches to the surface and as a result the water is homogeneous from surface to bottom. Indeed the waters here never become stratified, since they are naturally homogeneous at the end of the winter, and the intense tidal stirring never ceases, so that the vernal warming never gets a chance to build up surface layers of sufficient stability to withstand the eddies.

As might be expected the bay of Fundy furnishes examples of every type of tidal mixing. The characteristic feature of the one just mentioned is that there is a sufficiently large body of turbulent water that the tidal ebb and flow does not introduce an appreciable quantity of stratified water from the neighbouring regions. Probably the head of a tidal bay is the only situation where this can occur. In other types of tidal mixing the mixing region is more localized with respect to the water that passes over it. We shall consider three such types which we shall call Quoddy mixing, shoal mixing, and passage mixing. In the Quoddy region of the bay of Fundy there are two land locked bays, Passamaquoddy and Cobscook, whose joint area is about 140 square miles (360 sq. km.). The tide runs in and out of these bays through two long narrow channels in which there is great turbulence and consequent mixing. At one end of the mixing channels are the restricted waters of the bays while at the other end is the open Fundy water. The result is an efficient mechanism for breaking down the stratification of a large volume of water. In shoal mixing we have tidal streams flowing from deep water over one or more shoals with a consequent variation of velocity. Eddy formation is facilitated by decreasing velocities as well as by the large irregularities of an uneven but shallow bottom. A series of shoals such as those off the SE coast of Grand Manan island will have a cumulative mixing effect which is noticeable locally rather than in the surrounding region. There is no continuous addition of fresh water within the region to accelerate the removal of mixed water. In the case of the Manan shoals the surface water at the NE end is lighter than at the S end, so that a horizontal density gradient is established. The resulting residual surface flow across the region is less than it would be if the shoals were absent. During a single tidal movement, flood or ebb, the transport of water across the shoals is not as large as the surface velocities might suggest, because the depth of water above the shoals is very small, while the motion of the deeper water between shoals is almost entirely rotational. Turbulence is so great that the vertical mixing at any one place is almost complete and the isosteres slope steeply downward from surface to bottom. The residual surface flow is a slow movement of water which gets progressively heavier instead of a current of water traceable by constant characteristics. To supply the heavy water for this progressive mixing there must be a bottom inflow to the region, but this movement will be so slow as to be masked by seasonal changes. The mixing produced by a small isolated bank such as Grand Manan bank will be scarcely noticeable either on the bank or around it. Turbulence will occur only in a small region on the down stream side of it and the veering of the tidal stream shifts this region around. Consequently the resulting mixing will not be cumulative and its effect on the density distributions will be scarcely observable. The most noticeable effect of the bank is an increased choppiness of the water due to its higher velocity. The surface water will also be colder and heavier than it is away from the bank, not because it is mixed but because the heavier sub-surface water has been carried up the slope of the bank by its greater momentum, displacing the lighter surface water from the area above the bank. After passing the bank, this heavier water will sink again to its normal level and if the density gradient of the surface waters is strong a line of convergence may occur where the sinking water meets and flows beneath the lighter layer. The writer has frequently observed this convergence on a small scale in the St. Croix river estuary. At Joe's point, where the estuary is opening out into Passamaquoddy bay there is a sand bar or shoal running out beneath the water for some distance. On the flood tide a sharp line of convergence may be seen where the heavier water brought up over the bar sinks again beneath the lighter water. The convergence is marked not only by a line of scum and floating material, but also by a difference in colour on either side. In addition when there is a light breeze against the tide the heavy water will be strongly rippled while the lighter water remains smooth. It is possible to measure the slope of the sinking water by observing the constant distance beyond the convergence line at which a two metre depth drag will remain. While such phenomena as these may be produced by an isolated bank, the mixing effects are undoubtedly small. The case of a large bank, such as Georges bank, is too complex for discussion here and will be dealt with later (Part III, sect. 2). The third type of local tidal mixing occurs in passages connecting two bodies of tidal water, as for example the passages between St. Mary bay and the bay of Fundy. Such passages are usually shallow and produce a mixing of the superficial layers which can be only of local importance. Deeper and wider channels such as Grand Manan channel must be studied individually.

There is a secondary effect of the tidal currents along broken shores which should be mentioned. If any mixing takes place along-shore the surface water will be heavier there than further off shore. Consequently there will be a slow surface current towards the shore and a sub-surface flow away from it. These currents will only be small components which are additive to the tidal current along-shore, but they may be of importance in causing drift bottles to go ashore.

5. Wind Effects

The general theory of wind driven currents in homogeneous water remote from obstructions has been worked out by Ekman. Account has been taken of the gradient currents and the bottom currents which arise with a wind blowing parallel to a coast. More recently Ekman has also developed the theory for the effect on the current field of the configuration of the sea bottom. In general a counter clockwise vortex tends to form where the depth increases in the direction of the current and a clockwise one where the depth decreases, while there is no disturbance where the current follows the contours. This effect is not restricted to wind currents but occurs with any gradient current however formed. An enclosed sea introduces boundary conditions which modify Ekman's results for wind currents considerably. Palmén (1930) has studied the wind driven currents in the gulf of Finland and shows how the velocities may be calculated from the resulting solenoidal field. Although he pays particular attention to winds parallel to the gulf, he also gives data for the velocity and deviation of currents produced by winds in all directions. From his results it appears that the range of wind directions which produce an inward component of surface current is only 140°, while winds from the remaining 220° produce an outward drift. This inequality in directions is due to the fact that water can not move to the right of the wind if the sea on the right is enclosed but will do so freely if it is open. Sandström (1919) gives a good account of the various possible effects of wind on currents, both in restricted basins and in the open sea. Harvey (1928) also reviews the effects of wind in shallow and enclosed seas. Illustrating the fact that the depth of a wind blown current is dependent on the homogeneity of the water he says "in the southern part of the North Sea strong tidal streams in the shallower water with uneven bottom set up increased turbulence in the water, which is here homogeneous, and in these areas wind-blown currents extend deeper and appear more effective in transporting planktonic organisms."

An important factor in the consideration of wind blown currents is the length of time required for their formation. During the period of acceleration the velocities will differ from their final steady value. In an enclosed sea the transport of surface water to the right of the wind builds up a pressure gradient at right angles to the wind and this in turn produces a deep gradient current in the same direction as the wind. If the steady state is reached there will no longer be any movement of the surface water to the right of the wind, unless there is a compensation current along the bottom to the left of the wind direction. Whether this occurs will depend on the stability of the water and the force of the wind. It is evidenced by upwelling of cold bottom water along the shore on the left of the wind direction. This latter phenomenon is of course frequently observed with an off-shore wind (Bigelow 1927, p. 588) but it can also occur on a shoreline parallel to the wind direction and to the left of it, as in the case at present under discussion. Since the direction of the wind blown current approaches that of the wind as the steady state is attained and since its final direction is dependent on the stability of the water layers, the time to establish a steady wind drift is of primary importance. Ekman calculates for the open sea above the continental shelf that the stationary state is established in a few days time, but that the surface current is established in a few hours time and responds quickly to changes in wind. In an enclosed sea, however, the boundary conditions compel an immediate dependence of the surface current on the deep gradient current, so that it will probably take one or two days for the wind driven currents to reach a steady state. It is to be noted that Palmén's observations which show the dependence of the solenoidal field on the wind are taken only when the wind has been reasonably constant for three days. If the region under consideration is not subject to steady winds for days at a time the wind driven currents will not be as important as those observed by Palmén.

If we now examine the available wind data for the bay of Fundy, we shall see that except for unusual gales the wind is only of secondary importance in determining the solenoidal field and the currents. Figure 7 shows the total mileage of wind from each direction during each month in 1932, as observed at point Lepreau, N.B., and at Yarmouth, N.S. Unfortunately there are no published data (other than the daily weather maps) from which one can obtain the duration and constancy of the wind from a particular direction. It has been the writer's experience in the bay of Fundy during the summer months that the wind increases during the day and then decreases after sunset. Furthermore there are often marked changes in the wind direction near the coast.

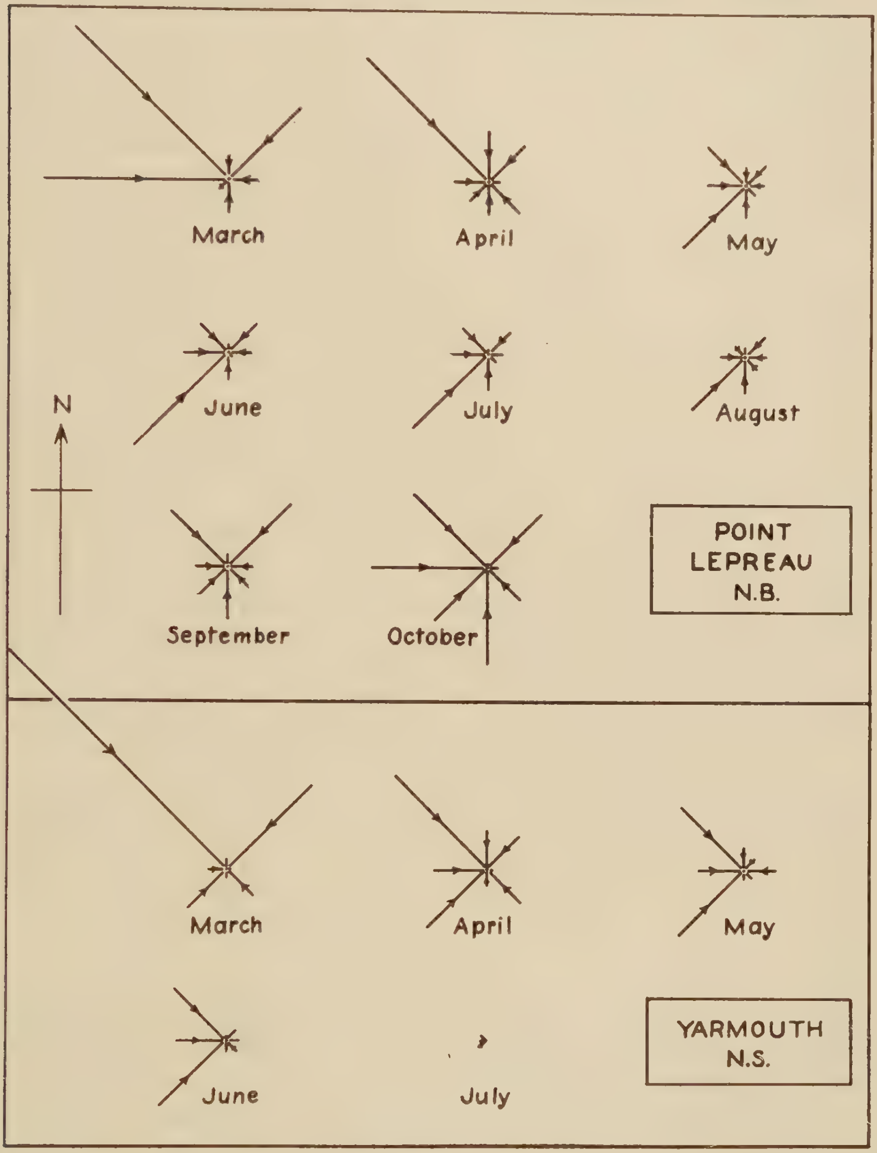

FIGURE 7. Monthly wind mileage in 1932 at Lepreau and at Yarmouth. (The NE wind mileage in September is approx. 2000 miles).

Data for the frequency of winds in the gulf of Maine and their effect on the circulation are given by Bigelow (1927, pp. 962-970). The Fundy winds are much the same as in the gulf of Maine, northwesterly in winter and southwesterly in summer. The chief points of difference in the bay of Fundy are the shallower depth and resulting homogeneity and the more complete enclosure of the surface layers. The influence of the diurnal warming and cooling of the land also produces a greater variation in the Fundy winds. On the basis of Palmén's observations it seems probable that winds from the S, SW and W will produce a surface drift into the bay while winds from the NW, N, NE, E and SE will drive surface water out of the bay. There may of course be a horizontal circulation as well as a vertical one, and the wind drift referred to is the resultant surface drift in or out across the whole width of the bay. Bigelow's deductions for the wind driven currents in the neighbouring part of the gulf of Maine are as follows. In summer the prevailing winds will drive surface water from the gulf towards Nova Scotia with a resultant movement northerly into the bay of Fundy. This is well borne out by drift bottle results. On the Maine coast east of Mount Desert there is a compensating outward flow which is against the prevailing wind. It is possible that the stability may be sufficiently low to allow of upwelling and a vertical circulation when the offshore winds are sufficiently strong. He also suggests that the tail of low salinity water from the Saint John river southward in April may be caused by the northwest winds.

Since it is well known that the bay of Fundy contains water that is homogeneous it would seem to be especially susceptible to the effects of winds. However, an examination of the observations will show that only certain regions are homogeneous, while others are unusually stable in the surface layers as a result of the inflow of fresh water from the rivers. Wind effects may predominate in the water at the head of the bay and perhaps in the Grand Manan channel region, but the main circulation of the bay is undoubtedly due to gravity forces. The wind is mainly responsible for the confusing complexities which cause such differences in detail between sets of observations which one would otherwise expect to agree.

There is no doubt that winds of unusual strength and duration may have a very great effect in the bay of Fundy. In particular such a wind from the NE in the summer would drive surface water out into the gulf of Maine, with a compensating indraught of bottom water. If a storm centre passes over southern New Brunswick the wind will blow up the bay and increase the tide, but if it passes over Nova Scotia or further east the wind will blow out of the bay. The most striking case was the famous Saxby tide of October 5, 1869. A severe gale up the bay occurred on a day when the moon was new and also in perigee, with the result that at high water the level in Cumberland basin was raised 6.2 feet above the normal height at perigee springs (Dawson 1920, p. 27). It is of interest to note that at the succeeding low water the level fell as much below ordinary low water as it had been raised above ordinary high water (Dawson 1917, p. 92).

6. The determination of the Residual Currents

The residual currents in the bay of Fundy are unusually difficult to detect because of the predominance of the tidal currents. While the latter are of importance to navigation the residual currents control the interchange of plankton, nutrient salts and heat energy between the bay and the neighbouring gulf of Maine. The methods available for the determination of these currents are:

(*a*) the vectorial analysis of current velocities measured over a tidal cycle,

(*b*) the charting of drift-bottles returns,

(*c*) the interpretation of horizontal and vertical sections showing the temperature, salinity and density distribution,

(*d*) the use of T-S diagrams to trace the history of the water,

(*e*) the calculation of dynamic heights and the charting of dynamic isobaths,

(*f*) the correlation of physical observations with biological evidence.

We shall discuss each of these methods with regard to its application to the bay of Fundy, and show why no one method has yet been able to give a satisfactory solution.

Current measurements by Dawson (1908) at various points in the bay led him to the conclusion that there was no general movement of the water in any one direction which was at all well marked. However, Mavor (1922) has shown from these same measurements that there is a definite displacement of the water at the end of a tidal cycle. By using the average velocity during each hour and adding the corresponding displacements graphically the resultant displacement is easily obtained. Mavor determined this for each of Dawson's stations. It should be pointed out that the vectorial addition of the hourly displacements is only valid if the velocity of the particular water particle under consideration is at every instant the same as the velocity of the water measured at the anchored ship. This is approximately true in regions far from shore where the bottom is uniform, but in so small and irregular a region as the bay of Fundy there are great differences in the currents at points quite close together. Consequently it is unwise to place too much reliance on the quantitative results which Mavor obtains in this way.

The analysis of surface currents by drift bottle returns has been widely used, but it is a method which can be misleading unless the greatest caution is used in interpreting the returns. The finding of a bottle is the result of a number of chances among which are the simultaneous occurrence of a beach and an on-shore wind. In the absence of wind there is a shoreward movement of the surface waters wherever there is strong tidal mixing along shore, so that in such places the bottles will tend to get broken or to be stranded where they will not be found. Bigelow (1927, page 867), in discussing the validity of these returns, mentions the fact that the drift of a bottle does not necessarily reproduce the drift that would have been followed by a particle of water, because the bottle floats on the surface, while the water may sink as new water rises from below to take its place. This is of particular importance in the bay of Fundy where the stability is low and vertical circulation does take place. A good account of drift bottle experiments during August and September is given by Mavor (1922).

The distribution of temperature and salinity is commonly used to trace the movements of sea water. This is possible because the concentration gradients in the sea are usually so small that the effects of diffusion are practically negligible. Indeed it is now recognized that the changes in concentration or temperature which do take place are due not to molecular diffusion but to eddy viscosity. The normal distribution of sea water at rest would be a horizontal stratification with density increasing with depth. Any motion of the water tends to disturb this distribution in such a way that gravity forces are produced to balance the dynamic forces of the moving water. If a steady state is reached we may deduce the motion of the water by observing the distribution of the density. The separate variants of temperature and salinity help to identify and trace the moving bodies of water. Unfortunately the movements of the water become so complicated when tidal currents are present that there is often considerable doubt as to the validity of temperature, salinity or density sections constructed from isolated sets of observations. Repeated observations in a region will give certain consistent results which can be separated from the temporary variations, but it is not always possible to obtain successive sets of observations at each station. The writer has attempted to minimize the tidal variations by taking simultaneous sections from two boats or else by comparing sections taken on the same phase of successive tides.

The constancy of the salinity and temperature of a mass of water in the sea is effectively utilized in the T-S diagram method of tracing the circulation. Temperature and salinity are used as coordinates and the depth is noted in figures beside the plotted point. Points representing conditions at various depths for one station are joined by a smooth curve. The use of these diagrams is well illustrated by Jacobsen (1929) in his analysis of the movements of North Atlantic waters. They are most valuable when the waters of a region are composed of varying proportions of two or more source waters of definite salinity and temperature. The bay of Fundy has no other sources than fresh water and the waters from the gulf of Maine. As the latter are continuously variable between limits rather than composed of several different types the T-S diagram is not very fruitful for the bay in general, but there are a number of local cases in which it gives valuable information as to the origin of the water. An improvement to the diagram is to draw on it a set of curves for equal densities. The vertical distribution of temperature salinity and density can then be shown simultaneously by a single curve for each station.

The last and most formal physical method of attack on the problem is the calculation for each station of the dynamic height of water above the bottom or above some level at which the water movements are negligible. A dynamic topographic chart is plotted in which the contours are dynamic isobaths. The water flows along the contours and the current strength is proportional to the gradient which is calculable from the distance between the isobaths. In shallow seas such as the gulf of Maine and the bay of Fundy it is necessary to calculate the gradient between pairs of adjacent stations and to determine the dynamic heights relative to some one chosen station. When the two adjacent stations are of different depths the water between them and below the bottom level of the shallower station will in general be in motion and the dynamic gradient at the surface can only be obtained by applying an approximate correction for the gradient due to this moving bottom water. In the bay of Fundy the change in depth between adjacent stations is often a large fraction of the depth, with the consequence that the uncertain gradient due to the bottom current is nearly as large as the gradient obtained from the difference in weight of the upper waters. A further source of uncertainty lies in the fact that owing to the strong tidal currents throughout the bay it is unsafe to lower the water bottles very close to the bottom and as a result the true bottom densities are not obtained. In future work it would be advisable to use a heavily constructed water bottle of the insulating type which could be lowered right on to the bottom with safety.

In a preliminary study of large regions the occurrence and distribution of plankton often furnishes the first indication of the circulation in the region. On the other hand when the water in a region is as nearly homogeneous in character as in the bay of Fundy the indications of one species contradict those of another species and it seems that there are too many factors affecting their distribution for plankton to be of much use in determining the residual currents. The phytoplankton is so much more at the mercy of the water movements than the zooplankton that it does give considerable confirmatory evidence about the circulation in restricted regions. But even with the phytoplankton the response to light must constantly be borne in mind so that changes in distribution shall not be attributed solely to the movement of the water. It is fortunate that in this investigation the phytoplankton studies were carried out during the same period as the hydrographic measurements, for these two branches of the investigations were most helpful to each other.

PART II. ANALYSIS OF OBSERVATIONS

1. Arrangement and Nomenclature

The observations obtained in the bay of Fundy during 1932 were not complete enough for a presentation of temperature and salinity conditions in successive months over the whole area. It must be remembered that the main object of the investigation was not the oceanography of the bay of Fundy in general, but the particular part played by the Quoddy mixing mechanism. It seems best to present the observations in the order in which they were obtained and to discuss important local features as they become apparent. It will be found that vertical sections are used more commonly than horizontal ones, for owing to the low stability of the region the movement of any particular body of water is seldom restricted to a horizontal plane. For the same reson it is better to study the distribution of density, salinity and temperature together rather than separately.

A key chart to the hydrographic stations occupied is given in figure 1. The stations are arranged in lines running from one prominent shore point to another, or else running out to sea in a straight line from a shore point. All stations on one line are numbered outward from the shore and are prefixed by one or two letters which designate the shore point from which the line starts. Thus S3 is the third station from shore on the line extending out to sea from Swallow Tail lighthouse. Stations on the two longest lines crossing the bay are given numbers without any prefix since they are too far from shore to be referred to it. Single stations in narrow passages are denoted by two letters, chosen from the names of the places used to locate them, as for example S-H which is a station between Spruce island and Head harbour. This system of nomenclature is particularly suitable for a region of the size of the bay of Fundy since the name of each station conveys sufficient information for any one familiar with the region to locate it mentally without having to refer each time to a key chart. Since observations are often made at the same station at frequent intervals it is necessary to specify the date and time rather than a cruise number. On the other hand the plankton stations were taken on monthly cruises extending over a much larger area, so that a different system of nomenclature was more suitable. Plankton station 25.05 means station 5, as found from a key chart, taken on cruise 25. It should be pointed out that owing to the variety of work carried out at the plankton stations the hydrographic observations were usually taken in two series, as much as a hour apart, with a consequent lack of simultaneity and uncertainty of position. At the hydrographic stations on the other hand every effort was made to have the position exact and to complete the observations in a minimum time, about 25 minutes at the deepest stations. For qualitative purposes however the hydrographic data from the plankton stations is a valuable addition to that obtained at the purely hydrographic stations.

In order to clarify references to the various regions in the bay of Fundy the following nomenclature will be used in all reports made on the investigations for the International Passamaquoddy Fisheries Commission. The **QUODDY REGION** comprises the whole body of water which lies within a line drawn from West Quoddy Head to the northern extremity of Grand Manan island and on to point Lepreau. Further subdivisions of the Quoddy Region are: **Passamaquoddy bay,** or the inner bay, lying inside of Deer island and not including any part of the passages which connect it to the outside waters; **Cobscook bay,** lying within a line drawn from Eastport to Lubec; and the **Quoddy passages,** which include the entrance passages to these two bays together with the waters among the many small islands outside Deer island as far as a line drawn from East Quoddy head (or Head Harbour light) to Bliss island; and finally the **Outer Quoddy region** which is that part of the Quoddy region lying outside of this line and within the line from West Quoddy head to Grand Manan and on to point Lepreau. **GRAND MANAN CHANNEL** is the body of water between Grand Manan island and the coast of Maine extending from the Quoddy region to a line drawn from Machias bay, Maine, to Machias Seal island and up to Southwest head, Grand Manan. The **BAY OF FUNDY** extends in a northeasterly direction from the gulf of Maine and the position of any line chosen to divide the two regions for purposes of reference must be somewhat arbitrary. We shall consider the boundary of the bay of Fundy to extend from Machias bay, Maine, to Grand Manan bank and across to Brier island, N.S. The name bay of Fundy will be used to represent the entire bay in distinction to the gulf of Maine, and also the major portion of the bay excluding the Quoddy region and Grand Manan channel in distinction to either or both of these local areas.

2. Conditions in Winter and early Spring

During the winter of 1931-32 observations were taken at stations in Passamaquoddy bay, the Outer Quoddy region and the Fundy deep. The salinity values were destroyed by fire but the temperatures are given on page 196, and in the hydrographic tables. In the Fundy deep the lowest surface temperature was probably about 2°, early in March, and at 50 metres 2.7° in the middle of March. In Passamaquoddy bay temperatures are lower, although the tidal stirring and admixture of deep water from outside prevents the temperature falling as low as one might expect for such a land locked basin. Early in February the formation of an ice sheet in the harbour prevented the use of the boat for a time, but from the observations taken it would appear that the temperature difference of about 1° between surface and 25 metres persists even into February. On March 1 this difference had disappeared. It is noteworthy that in the Fundy deep the water below 10 metres had risen from 2.9° to 3.7° between March 5 and April 21. From the air temperatures at Eastport, Maine, during this period (see fig. 8) it does not seem possible that this was due to direct solar warming alone, especially as the water from the coastal regions is still colder.

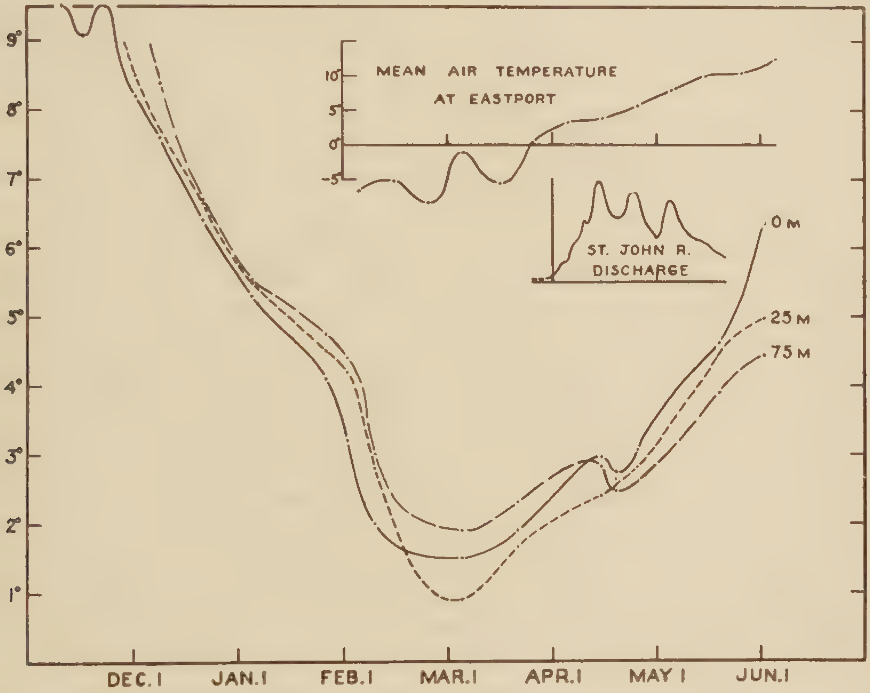

Figure 8. Water temperature at station 5, Outer Quoddy region, with contemporary air temperature at Eastport and fresh water discharge at Saint John.

The rise in temperature must be due to the inflow of warmer water from the gulf of Maine. The progress of this water from the Eastern channel of the gulf of Maine is well shown by Bigelow (1927, figs. 12, 24, and 192) in his temperature charts for 40 metres.

In the Outer Quoddy region temperatures show the influence of the nearby bays and of water from the Saint John region. Figure 8 shows the contemporary progress of the water temperature at sta. 5 (Quoddy region, lat. 44° 57′, long. 66° 49′), the air temperature at Eastport, Maine, and the volume of the Saint John river discharge. At the end of February the water in Passamaquoddy and Cobscook bays is undergoing severe cooling, especially at the intertidal zone along the shore. Owing to the strong tidal movements this chilled marginal water does not remain near shore but is rapidly distributed throughout the whole volume of water in the bays. This tidal interchange is also the reason why the water does not reach as low a temperature as in bays much farther south, as for example in Cape Cod bay. When the chilled water emerges from the bays into the outer Quoddy region it finds its density level below the surface. At sta. 5 its influence on the 25 metre thermogram is most noticeable around March 1 when the temperature at that level is the same as within the bay, while at the surface and below 40 metres it is more than 0.6° higher. The relative density of the water emerging from the Quoddy passages at any time is dependent on the amount of fresh water inflow to the bays and on the supply of heavy bottom water to the mixing mechanism of the passages. In the earlier part of the winter, overturning has almost equalized the density of the outer Quoddy waters from surface to bottom, but the rivers are still supplying fresh water to the bays in sufficient quantity to cause the mixed water from the passages to be lighter than any water outside, so that the outflow will be mainly in the surface layers. During February, however, the river discharge falls to its minimum for the year and there is not sufficient fresh water to make up for the increase in density due to the extra cooling, with the result that at sta. 5 the outflow is found at the 25 metre level rather than at the surface. Since the reduction of the fresh water is itself due to the low air temperatures the two factors affecting the density work simultaneously to shift the level of the outflow downward and to cool the 25 metre water rapidly during February. In 1932 the river outflow in March remained as small as in February (see fig. 5), though this is not always the case, and it was not until late April that the arrival of the freshet water together with the vernal warming restored the vertical temperature distribution curve at sta. 5 to its normal summer shape.

3. April Conditions; the St. John River and the Spring Freshets

The variation in the time of occurrence and volume of the spring freshets has already been discussed (Part I, sect. 3). In 1932 the Saint John freshets began about April 2 and reached a maximum on April 14 and 15. This event marks the beginning of rapid changes in the oceanography of the bay and constitutes one of the greatest single factors in its subsequent development. Before tracing the Saint John water we must examine the unusual conditions in the mouth of the river produced by the so called "reversing falls."

The Saint John river empties into the sea from a large fresh water basin through a rocky gorge about 4 miles (6.5 km.) in length. About half way along this gorge there is a constriction which reduces its width to less than 100 yards (90 m.). With the inner basin acting as a reservoir the water cannot flow through the channel rapidly enough for the level inside to keep pace with the tidal level outside. For a period at low water there is a fall of several feet at the water passes outward through the constriction, while on the inward flow as high water there is a somewhat smaller fall in the opposite direction. During great freshets the height of the river may be such that the inward fall does not occur. Between the periods when the water falls in opposite directions there is a time when the current slackens and turns and for a period of about half an hour before and after the time of slack water navigation is quite practicable. This slack water normally occurs at the end of the inward run 2 hours, 25 min. after high water, and at the end of the outward run 3 hours 50 min. after low water. While this phenomenon of a reversing falls is not quite as spectacular as its name might suggest it rarely occurs on such a scale in a natural watercourse and has consequently become widely known. From the oceanographic viewpoint however it is interesting because the estuarial conditions here are unique and have a profound influence on the western part of the bay of Fundy. In most estuaries where the tidal range is large (Severn estuary, Gibson 1933; Penobscot bay, Seiwell 1932) the change in salinity from surface to bottom is not as great as from station to station and on reaching the sea the water is not markedly stratified. At Saint John the waters of intermediate salinity flow outward in a surface layer about 5 metres thick, within which the density gradient is steep, while below this the water is almost undiluted and homogeneous Fundy water. It is well known that any such mixing mechanism which produces a surface outflow of water of intermediate salinity must consume salt bottom water, which therefore flows in towards the mixing region. Navigators are warned that within Partridge island the outward surface flow may still be evident after half-tide rising while at a depth varying with the stage of the tide a strong inward current may exist. The sharp change in density gradient which occurs at a depth somewhere between 5 and 10 metres may be found not only just outside Saint John harbour, but even 40 miles (74 km.) away off Grand Manan island (see fig. 9). The effect of this surface outflow is described in the next section, and a discussion of its remarkable resistance to vertical mixing will be found in Part III, section 1.

The spring freshets may be accompanied by another seasonal event, the occurrence of the maximum spring tides. These are produced when the moon is at perigee, at the same time as it is new or full. These high tides usually occur in the spring months and again at the end of the summer, but the dates are very variable from year to year. In 1932 maximum spring tides were on April 20-23, just after the commencement of the freshets. Observations were taken at sta. 5 on April 19 and 20 and again on April 25 and 26, before and after the spring tides, and at the mid-point of the northern end of Grand Manan channel on April 22 during the spring tides. The outstanding feature of these observations is the variability of conditions at sta. 5, both with the stage of tide and with the wind.

By comparing the averages for each depth of all observations on the 19th and 20th with those on the 25th and 26th it appears that after the strong tides there is an increase of salinity at all depths with a decrease of stratification. It seems that both at high water and at low water a strong south wind freshens the water at all depths, but especially at the surface (see L.W. on April 19 and H.W. on April 25). There are two possible sources for this fresher water, the outflow from the Quoddy passages which may normally pass to the west and south of sta. 5, and the channel between Grand Manan and the Wolves. The former is unlikely because the surface water at the Grand Manan channel station on April 22 at the end of the ebb and with a light NW wind is not as fresh as the south wind surface water at sta. 5. On the other hand the observations taken on April 21 at plankton sta. 6, which is just north of Grand Manan island, show that the water there is much colder at all depths and fresher down to about 30 metres than at sta. 5. The lowest temperature at sta. 6 is 1.4°C. at the 25 metre level. This cold water may be partly the Quoddy outflow at the end of February (see sect. 2) which has slowly worked its way to the north of Grand Manan, getting slightly warmer during March, but protected by the stable surface layers after the commencement of the freshets. For the same reason the coldest water found in the bay of Fundy during April is the sub-surface water between Saint John and Lepreau. On April 18 the water at 10 metres depth off Lepreau was just below zero degrees in temperature. Even before the freshets in April the outflow from the Saint John river was sufficient to produce a surface layer as far as Lepreau which was stable enough to protect the water beneath from the vernal warming.

The observations at the northern end of Grand Manan channel on April 22, during maximum tides, show that the dominant drift through the channel is towards the Quoddy region. At high water the water at all depths below 10 metres was completely homogeneous. At low water it is stratified, but below 10 metres much salter and slightly colder than at high water. This means that though some Quoddy water may enter the channel during the ebb tide it is completely driven out by the end of the succeeding flood tide, since at high water the water shows no trace of mixture with Quoddy water. During the ebb tide some of the deeper water which enters the channel must have come around the northern end of the island, for below 10 metres it is more saline than any sta. 5 water, but intermediate between the homogeneous channel water and the sta. 6 water below 35 metres. The slightly fresher surface water may have come from sta. 5 or else directly from the Lubec channel.

To summarize the conditions in the Outer Quoddy region at this time we can say that it is the meeting place of many waters, where the variable conditions of wind, tide and freshets preclude any constant circulation. If water enters the region from the Quoddy passages, from Grand Manan channel and occasionally at some level from sta. 6, it must obviously flow outward somewhere. It is difficult to say what the effect of the prevailing NW wind would be, except that it would tend to drive the surface water out of the region. We have no observations at this time from the shallow channel north of the Wolves and it is possible that there is a clockwise circulation around the Wolves. This would agree with the movement of the Saint John outflow, for the Outer Quoddy region would then

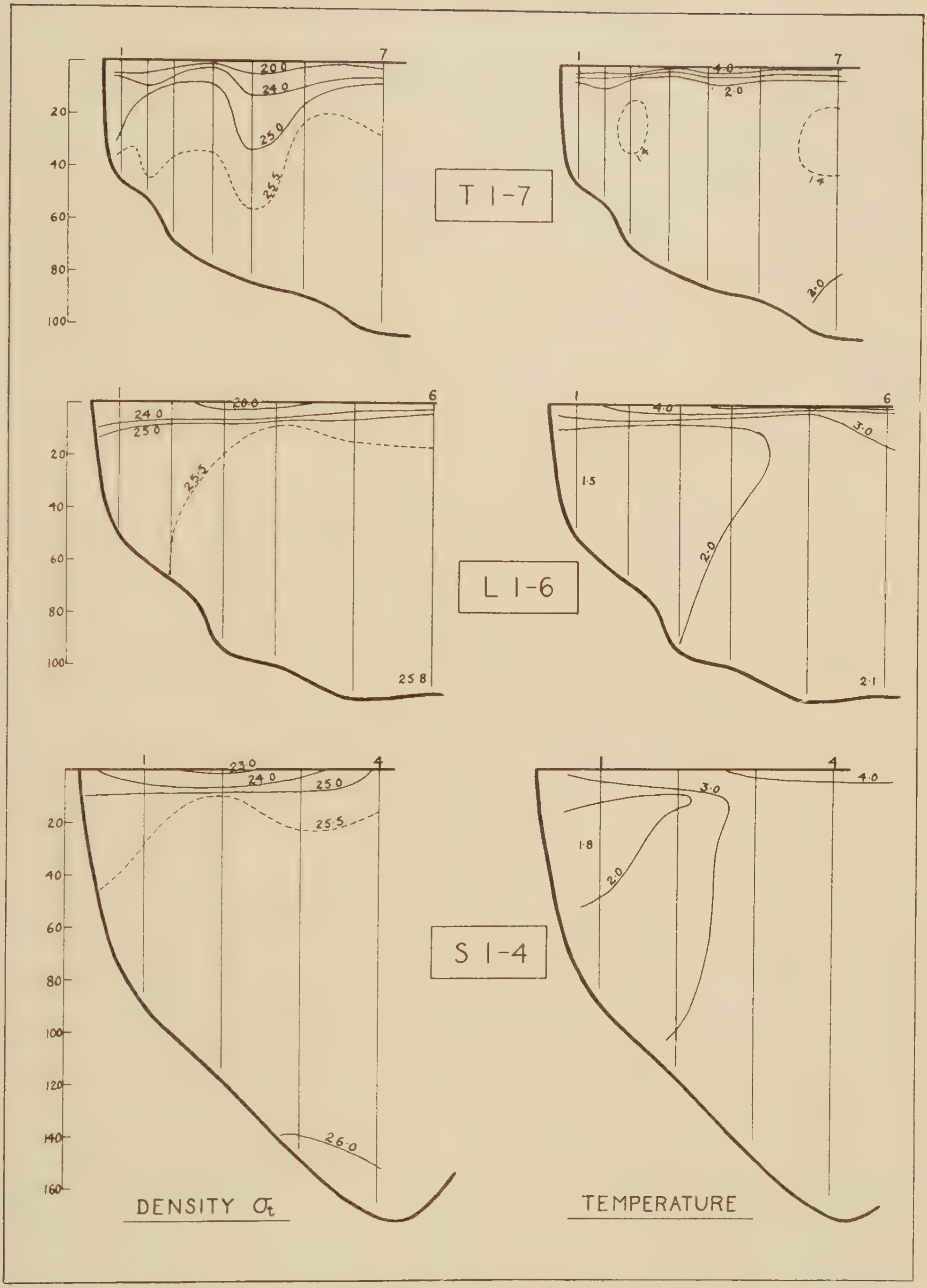

FIGURE 9. σ_t (density) and temperature sections across the Saint John outflow, April 30-May 4, 1932.

contain a large residual eddy generated by the residual surface drift sweeping past from Lepreau to the east of Grand Manan. One has constantly to remember that any residual current in the bay of Fundy is a slow movement composed of the differences between successive tidal displacements. It is bold to speak of an eddy when referring to residual movements of a circulatory nature but the justification is that the differences, as well as the tidal currents themselves, must fulfil the laws of continuity. Consequently a residual current moving past an abrupt opening in the coast line may be said to generate a residual eddy within the opening, provided we understand that the detailed motion in this eddy is not a simple circulation. If future observations show that water does not leave the region by means of such a clockwise eddy around the Wolves then the only other possibility is that it passes out between the Wolves and Grand Manan as a subsurface layer, and that its rate of progress is so slow that water which originated in the passages at the end of February is found north of Grand Manan at 25 metres on April 21.

4. THE SAINT JOHN OUTFLOW, APRIL 30-MAY 4

In 1932, at the end of April, the Saint John freshets had been running at full strength for over three weeks and it seemed to be the most favourable time to study the outflow. The stations chosen were located 3 miles (5.6 km.) apart or less on lines running out to sea from Tiner point, point Lepreau and Swallow Tail, so as to give three vertical sections across the probable course of the outflow. Each section took about 4½ hours and was made between half ebb and the succeeding half flood, so that they may be regarded as low water sections. Figure 9 shows the densities and temperatures for each section, while figure 10 shows the horizontal distribution of salinity at the surface. Salinity sections are not shown as they correspond closely to the density sections, owing to the small temperature range. The actual salinity values can be found from the tables, but roughly the isoline for $\sigma_t = 24.0$ corresponds to an isohaline for $S = 30.1^0/_{00}$ and $\sigma_t = 25.0$ to $S = 31.3^0/_{00}$.*

We have seen that the Saint John outflow emerges from the harbour as a surface layer 5 to 10 metres thick with a very strong density gradient, flowing over water which is almost homogeneous. The subsequent history of this surface layer may be traced in the sections of figure 9. Between Saint John and Tiner point the most violent adjustments are being made, for the velocity of the surface flow is being checked by friction with the homogeneous tidal water beneath. Moreover, since Tiner point is only 9 miles (16.7 km.) from Saint John, the river outflow is still somewhat intermittent and has not yet had time to spread into an even layer. In each of the sections the whole of the deeper water lies between $\sigma_t = 25.0$ and $\sigma_t = 26.0$, so we may consider $\sigma_t = 25.0$ as the dividing surface between the stratified layer and the deeper homogeneous water. The velocity gradient across the $\sigma_t = 25$ surface causes vertical mixing and the mixing increases the volume of stratified water at the expense of its stability. Since the quantity of water heavier than $\sigma_t = 25$ is very large there is no noticeable change in it, but the surface water becomes progressively heavier. Comparing the three sections in order we see that σ_t for the lightest surface water increases from 16 off Tiner to 23 off Swallow Tail. One would expect the $\sigma_t = 25$ surface to get deeper along the line of flow, but the horizontal spreading of the surface layer compensates for its tendency to thicken with the result that the Lepreau and Swallow Tail sections both show the $\sigma_t = 25$ surface at the same depth, about 10 metres. Beyond the Swallow Tail section the diminishing vertical density gradient in the surface layer is rapidly destroyed and its existence as a distinct layer comes to an end. The sections do not go far enough towards the Nova Scotian shore to show the limits of the surface layer in that direction but it seems probable from observations later in the month that there is a spreading of the light surface layer across the bay towards Digby as well as along the eastern slope of Grand Manan. However, the sections do cover the region where the surface layer has the greatest stability and we may now consider the effect of this layer on the temperature of the water beneath it.

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*NOTE.—The word "isoline" is used in this paper as a general word referring inclusively to isotherms, isohalines and isopycnals. In spite of being a hybrid word its simplicity and obvious meaning seem to justify its use in preference to the word "isogram", which suggests a line traced by a recording instrument rather than one drawn through points where the interpolated values are equal.

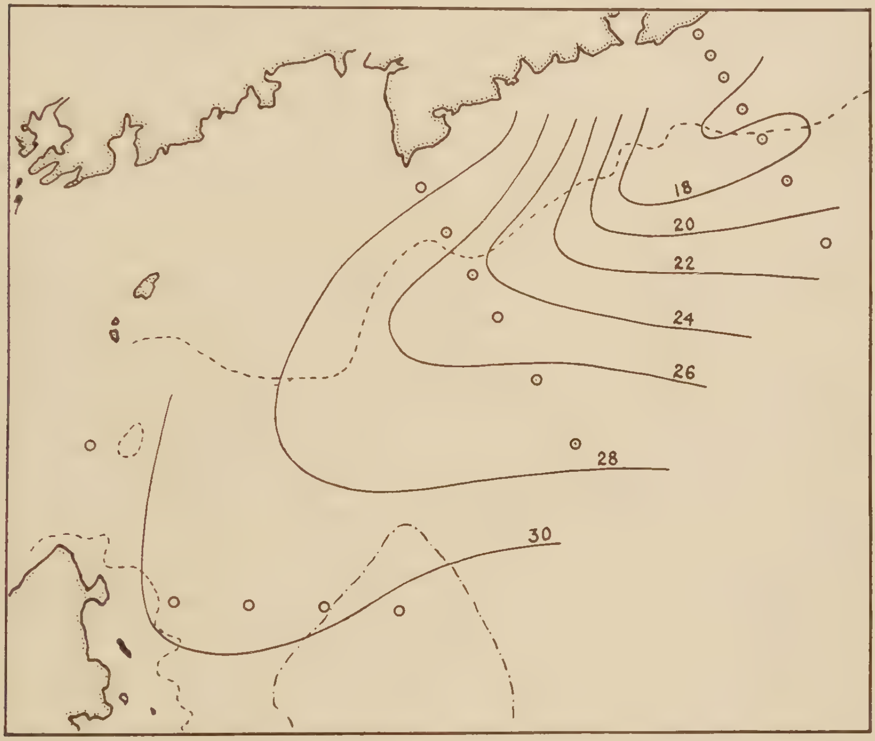

FIGURE 10. Surface salinity, Saint John to Grand Manan, April 30-May 4, 1932.

During the period of vernal warming heat is transferred downward through the water mainly by vertical mixing, for nearly all of the direct solar radiation is absorbed in the first 10 metres (see Bigelow 1927, pp. 674-680). If the surface layers are so stable that they are practically impenetrable to the eddies which effect vertical mixing, then there will be a negligible transfer of heat downward. Most of the heat absorbed will remain at the surface, where it is utilized in evaporation and in raising the temperature until thermal equilibrium with the air is reached. The average surface temperature along the Tiner and Lepreau sections is 4.6°, while the mean air temperature at this time is only about 7°. In contrast to the high surface temperatures we find that the insulating effect of the surface layer has preserved a body of water below the 10 metre level at a temperature between 1° and 2° (see temperature sections, fig. 9). This winter-cooled water, protected from vernal warming, is now the coldest body of water to be found within the bay of Fundy or the gulf of Maine. Off Tiner it extends beyond the end of the section, while at Lepreau and Swallow Tail it is found for about 10 miles (18 km.) off shore. The distribution of this cold water corres-

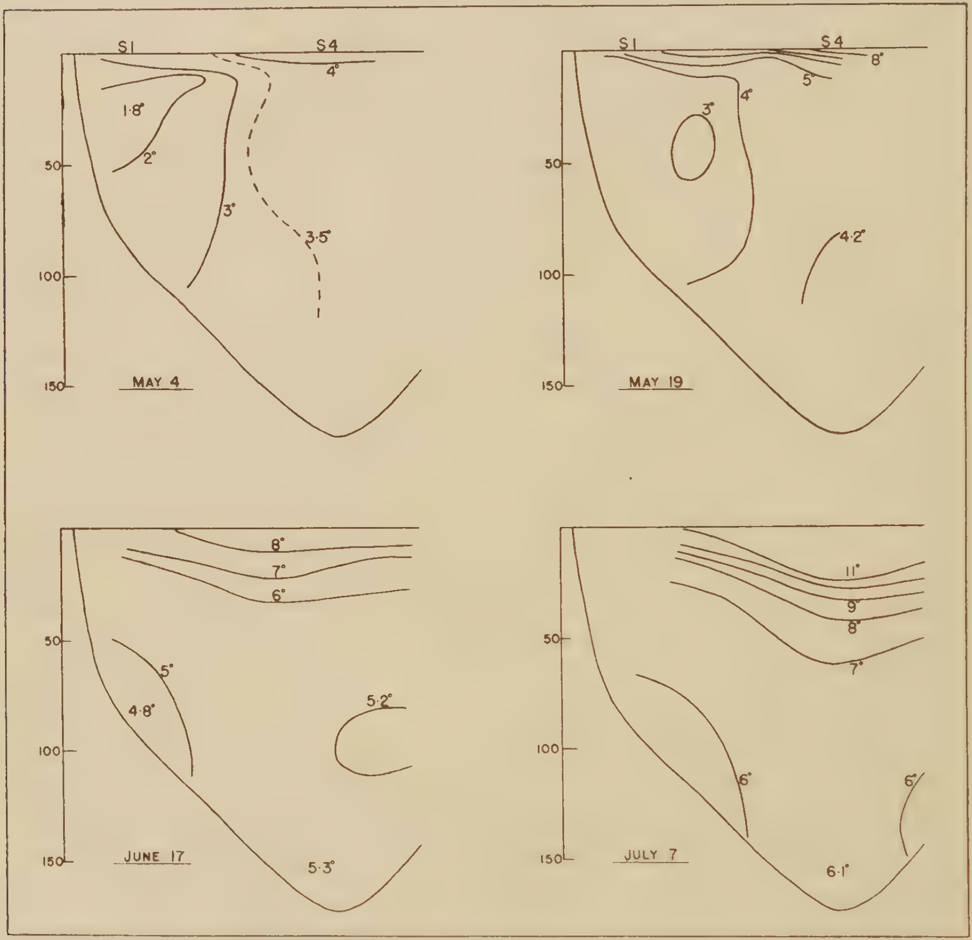

FIGURE 11. Vertical temperature sections, Swallow Tail, May, June, July, 1932.

ponds with that of water shoaler than 100 metres which lies below the stable surface layer. Whether it is continuous from Lepreau to Swallow Tail across the deep channel between them is uncertain, but from the similar characteristics of the water it seems probable. Since this water remains colder than the rest of the bay until well on in June it may be of importance biologically as well as physically. Figure 11 shows the temperature distribution in the Swallow Tail section on May 4, May 19, June 17 and July 7. As the season progresses the coldest water is found surviving at increasing depths since the upper levels warm most rapidly. The normal condition in the gulf of Maine is to have a minimum temperature at the lowest level to which the winter overturning has penetrated, usually about 100 metres on the coastal slope (Bigelow 1927, fig. 37). This level remains the coldest throughout the summer. The cold Fundy water which we are considering is a more local phenomenon and occurs at a higher level, about 25 metres at the beginning of May. Its proximity to the surface and the temperature range existing within a few metres may be of considerable importance to certain species of plankton. On the other hand the turbidity of the stable surface layer reduces the light intensity to a value found at greater depths elsewhere.

Between Saint John and point Lepreau the surface layer moves parallel to the coast with a velocity which Mavor (1922) estimates from drift bottle returns as 4 to 5 sea miles per day, or about 10 cm./sec., in August. We shall presently show from the hydrographic data that the maximum velocity on May 3 was about 30 cm./sec. Since this is quite an appreciable velocity we would expect the current to continue following the shore line on its right and flow into the Quoddy region, but it appears that the gravity forces tending to drive surface water away from the region are strong enough under normal conditions to resist the dynamic forces acting on the current The result is that it is forced offshore at Lepreau and flows towards the east side of Grand Manan. The balance between the Archimedean or gravity forces and the dynamic forces will be greatly influenced by the wind. A west or northwest wind will help to keep the Saint John current out of the Quoddy region while a south or southeast wind will tend to drive it inwards. A wind from the southwest, which is the prevailing direction in summer, will gradually push back the surface layer until its dynamic height is increased sufficiently for it to overcome resistance and spread to both sides. A measure of the gravity forces at any time may be obtained by comparing the dynamic heights of the water between the sea surface and the isobaric surface for 75 decibars (metres) at station 5 in the Quoddy region and at the station off Lepreau where the freshest surface water lies. This height D may be computed from the hydrographic data for

$$D = \int \alpha . dp = \Sigma \bar{\alpha} . \Delta p = \Sigma \alpha . \Delta_z \text{ dynamic metres,}$$

where α = specific volume in situ and z = depth in metres
$\bar{\alpha}$ = mean specific volume between two observed depths whose vertical distance apart is Δz.

The following table gives the heights for station 5 at various times with different wind conditions and the heights at L3 and L4 on the Lepreau section where the freshest water lay on May 3. In the table 73 metres has been deducted from each height and the decimal moved two places so that the figures are now dynamic cm.

Date	Tide	Wind	Sta. 5	L3	L4
April 19	L.W.	Strong S	20.00 cm.		
" 20	L.W.	Light NW	16.57		
	Maximum spring tides occurred on April 20-23				
" 25	L.W.	Light NW	15.27		
" 26	L.W.	. . . .	16.25		
May 3	1-2 hrs. flood	Fresh NW	. . . . .	16.13	14.82
May 31	Various times	SW to NW	16.3-16.8		
June 2	L.W.	S	17.3		

The table shows that the Quoddy region water at station 5 is in general dynamically higher than the water of the Saint John current. Its height is increased by a south wind and decreased by spring tides. The latter increase the rate of horizontal interchange and thereby increase the average density in regions where it is normally low. To say that station 5 is dynamically higher than the surrounding region merely means that the water there is on the average lighter than elsewhere. Why this should be so is not obvious, for it certainly is not necessarily fresher. Indeed if we calculate the mean salinity for station 5 on April 26 and for L3 on May 3 we get $31.48^0/_{00}$ and $31.42^0/_{00}$ respectively, so that the latter is fresher. But the water at station 5 is lighter because, surface temperatures notwithstanding, its average temperature is higher. The water below the Saint John current has remained low in temperature, insulated by the stable surface layers; while the water of the Quoddy region, stirred by the mixing mechanism of the passages, has been absorbing heat throughout its depth. Any serious change in the efficiency of this mixing mechanism brought about by the construction of dams for tidal power purposes might cause important changes in the residual currents at this time of the year. With an increase of stratification there would be slower heat absorption and a decrease in the dynamic height. The Saint John current might then sweep into the Outer Quoddy region and cold subsurface water would no longer be found on the eastern slope of Grand Manan.

We may use the dynamic heights obtained for stations L3 and L4 to determine the maximum surface velocity of the Saint John current, since these two stations lie on a section crossing the current at right angles and the median line of the freshest surface water passes between them. The latitude is 45° and the stations are 3.7 kilometres apart, hence we have

$$v_0 - v_{75} = \frac{(D_3 - D_4).10^5}{(14.58 \sin 45°)L} \text{ cm./sec.} = \frac{1.31\times10^3}{10.3\times3.7} = 34 \text{ cm./sec.}$$

Since from figure 9 the water at 75 metres is practically homogeneous between L3 and L4 there are no solenoids at this depth, so that $v_{75}=0$ and the surface velocity is 34 cm./sec. (0.7 knots) away from Saint John. This is the velocity of the residual current exclusive of the tidal movement. Actually the observations were made between one and two hours flood when the tide was flowing towards Saint John. From the hydrographic data it is possible to calculate the velocities across the section at all points and thus obtain a figure for the total transport of water across it at different depths.

5. THE CENTRAL EDDY AND THE GRAND MANAN SHOALS (MAY 18-19)

On May 18 and 19 three sections were made across the coastal slope on the east side of Grand Manan island. The object of these was primarily to determine the extent of influence of the shoals and rips as a mixing mechanism, and secondly to observe their effect on the stable surface layer of water which is produced by the Saint John current. The Swallow Tail section was placed as before while the two new ones were on either side of the series of shoals running out from White Head island to the Old Proprietor shoal. Hydrographic observations in this region are somewhat hazardous if the boat's engines are not reliable, because the tidal velocity over the shoals is from four to six knots and the bottom is uneven and rocky. Furthermore the rapid drifting of the boat makes it unsafe to lower the water bottles close to bottom. It would have been preferable to obtain these sections on the ebb tide, for comparison with the previous low water observations, but favourable weather conditions and a suitable opportunity occurred together only on the flood tide. The Proprietor section was started about an hour after low water and the White Head section finished by the succeeding high water, so that both sections were completed in the same flood tide. The Swallow Tail section was made at the end of the next flood tide. For comparison with figure 10 the surface salinity distribution is shown in figure 12. To aid in drawing the isohalines the surface salinites at plankton stations in neighbouring regions on May 22-24 are used.

By calculating the dynamic heights of the water above the 100 decibar surface for stations S2, S3 and S4 we obtain 97.51481, 97.50144 and 97.51428 dyn. metres respectively. From these we obtain the components of surface velocity at right angles to the section as 23.4 cm./sec. south between S2 and S3 and 22.4 cm./sec. north between S3 and S4. The distribution of salinity in figure 12, together with these velocity determinations, shows that there is a counterclockwise circulation about station S3. It will be seen from subsequent data (see fig. 15, sta. 17) that this is a permanent feature of the water movements in the bay and we shall refer to it as the central eddy. The light water supplied to it by the Saint John current is continuously being used up all around its periphery in vertical mixing, so that as we move away from it the surface salinity increases. This absorption of the surface water by mixing is most intense among the islands and shoals of Grand Manan, and consequently the $30.5^0/_{00}$ isohaline in figure 12 is drawn in towards this region. But the quantity of surface water absorbed from the central eddy by the Grand Manan shoals is only a small part of the total amount absorbed all around its long periphery. Here we have another example of a general observation on the behaviour of banks and shoals (cf. Part I, sect. 4), namely, that in spite of the very noticeable turmoil and mixing the bank water seems to be confined to the bank and is not found in any unusual quantity a short distance away. In figure 13 the density isolines are shown for the Proprietor and White Head sections. There is a striking difference in stratification between the two sections, although they are only about eight miles (15 km.) apart, and there does not seem to be any accumulation in the W H section of the almost homogeneous water of the P section. Thus the efficient vertical mixing in the shallow region east and southeast of Grand Manan affects the shape of the pool of light surface water but it does not play a major part in the consumption of this water. Nor is the quantity of intermediate mixed water which leaves the region very large, for it cannot be traced with any certainty.

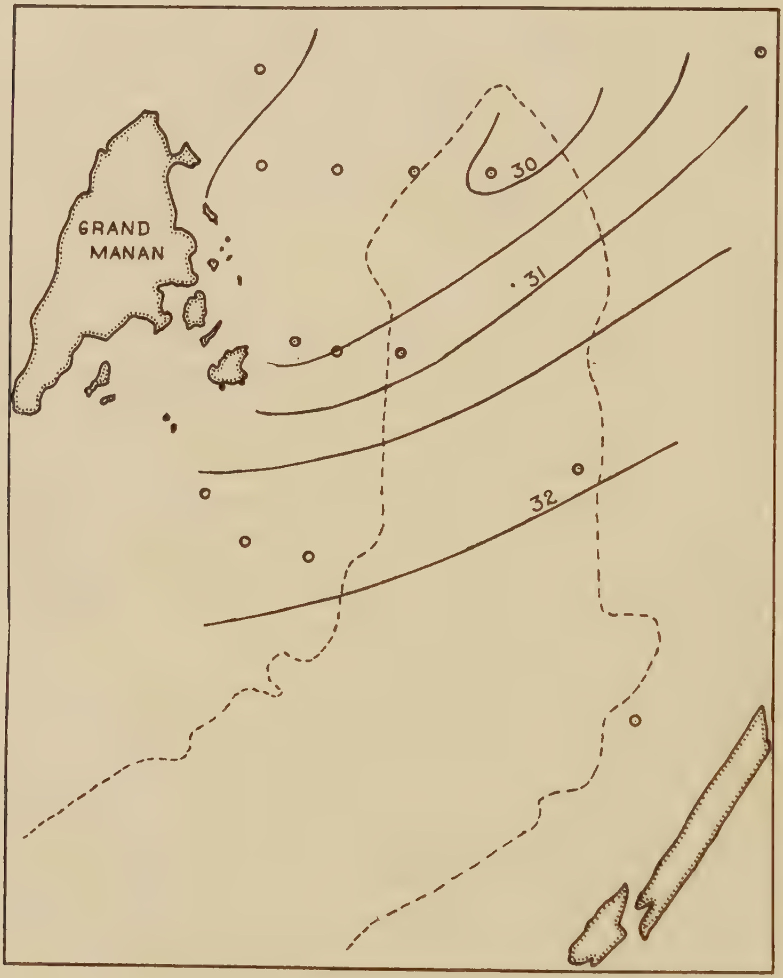

FIGURE 12. Surface salinity, May 18, 1932.

6. Grand Manan Channel (June 13); Homogeneous Water

One June 13 two pairs of simultaneous sections were made across each end of Grand Manan channel, at low water and at high water. The northern section lies between West Quoddy head and Indian beach while the southern section lies between Moose cove and South West head. The density sections are shown in figure 14. The Quoddy head section is much more stratified at low water than at high water and shows an intrusion of Quoddy water into the channel at all depths. Similarly the Moose cove section shows an intrusion of slightly stratified surface water from the south at high water. The region to the south of the channel is shallower and more effectively mixed than the Outer Quoddy region. The hydrographic observations suggest that the water in the channel and in the region just south of it may be stagnant as far as residual currents are concerned, even though the tidal currents are obviously strong. A further examination of the data with this possibility in mind gives interesting results. Consider the observations at station MC3 at high water. The density figures show a certain amount of stratification, especially in the top ten metres, but we find that this is due entirely to the temperature gradient, for the salinity is constant from surface to bottom. What is the history of water with such characteristics? If we take sea-water of salinity $32^0/_{00}$ and heat it from 5° to 7°, the water will expand while the mass of the salt remains the same, thus reducing the salinity to $31.99^0/_{00}$ and the density from $\sigma_t = 25.32$ to $\sigma_t = 25.08$. Heating has therefore produced a corresponding change in density without appreciably altering the salinity. It

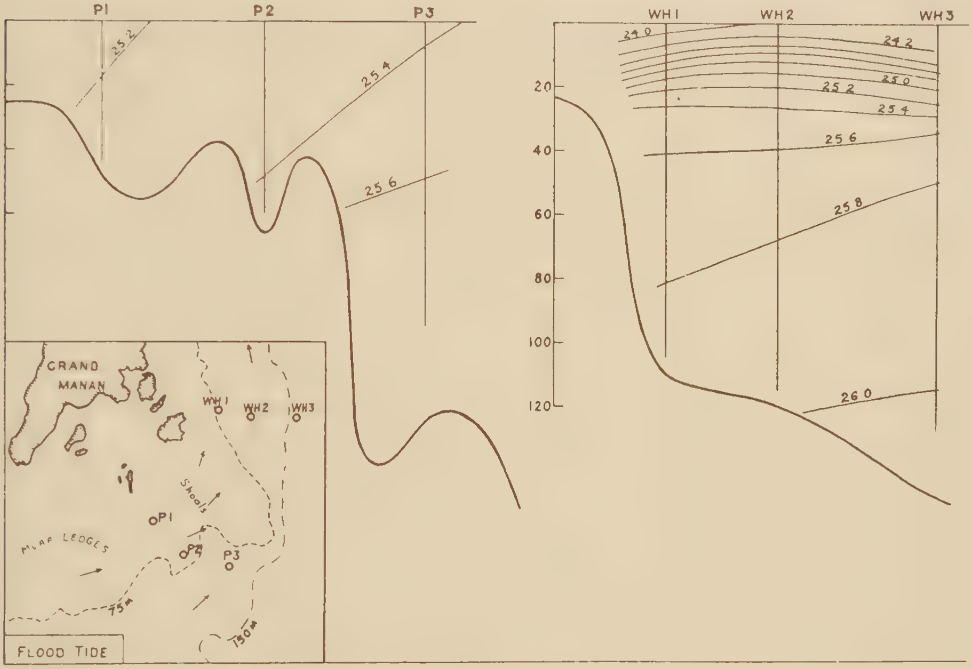

FIGURE 13. Vertical density sections off Grand Manan; values for σ_t, May 18, 1932.

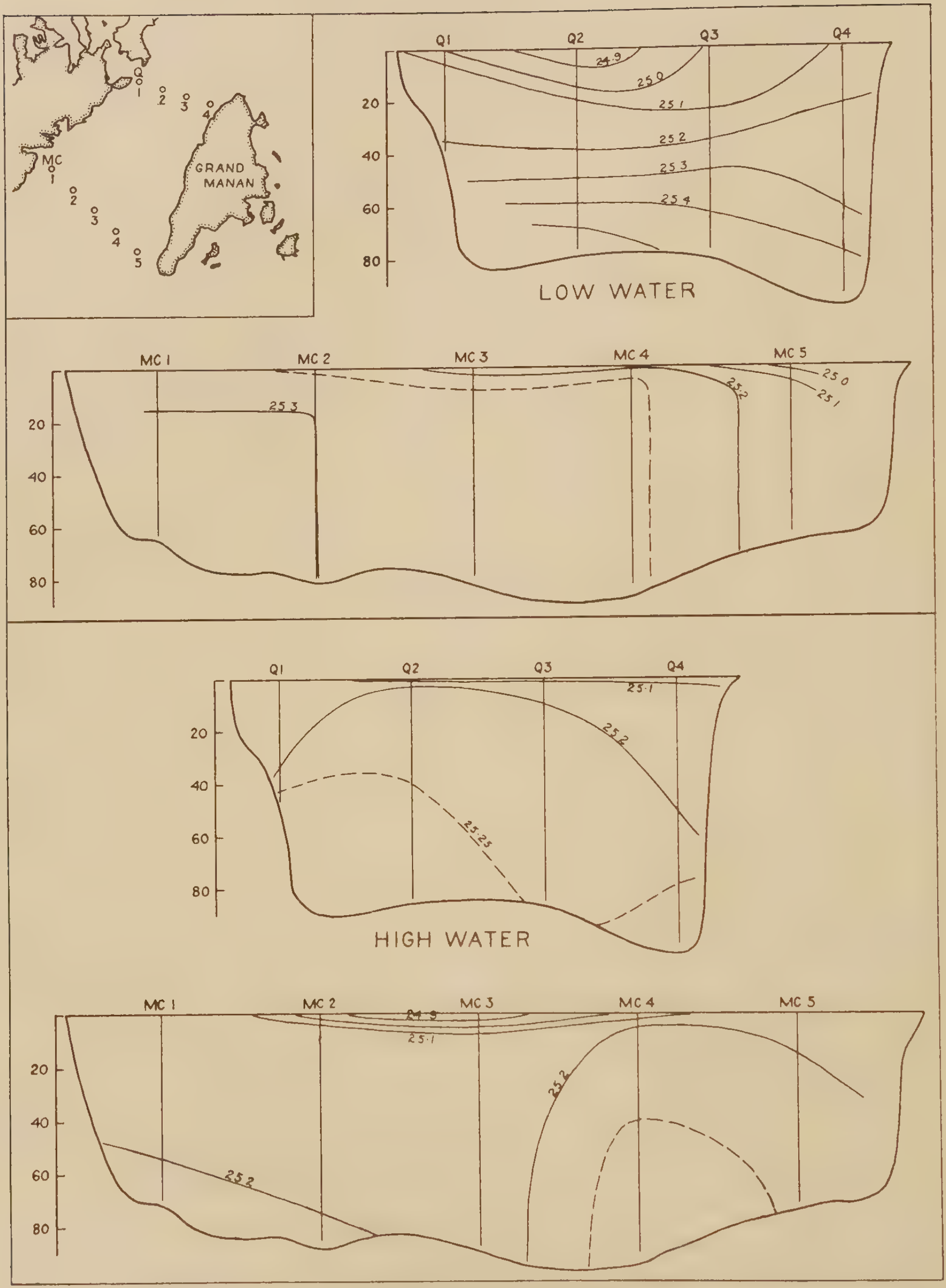

FIGURE 14. σ_t (density) sections, Grand Manan channel, June 13, 1932.

would appear that this water at station MC3 has at some previous time been thoroughly mixed and has since been undergoing vernal warming without further mixing. The latter condition will be met if the tidal velocities remain constant down to the depth at which stratification due to temperature is appreciable, in this case about 15 metres. Now the depth of the channel is remarkably uniform and the sides are smooth, so that the motion of the water is probably more nearly irrotational than usual. The velocity gradient will in such a case be very small or even zero for some distance below the surface and then increase rapidly near the bottom (Powell 1925).

Having shown how such temperature stratified water of constant salinity can exist in the channel we can now draw the conclusion that there is very little horizontal interchange at this time with the more stratified water of the Outer Quoddy region. The water to the south is already fairly homogeneous owing to continuous tidal mixing. Hence the constant salinity water in the channel has probably come in from the south but has remained long enough to acquire a temperature gradient of 2.4° in 10 metres. Therefore the residual current is directed northward but is small. During the summer months it may be largely due to the prevailing SW winds which would help to propel it in this direction. The consideration of conditions in Grand Manan channel has led to the establishment of certain general principles with regard to bodies of homogeneous water. These principles are applicable to coastal waters generally and are therefore presented in Part III, section 2.

7. June Hydrographic Survey of Bay of Fundy

By using both boats the whole bay of Fundy was covered by transverse hydrographic sections between June 15 and 18. The most important features of this survey have been presented in figures 15-18, while further information may be obtained from the tables of observations. Figures 15 and 16 show the distribution of density throughout the bay. The mixing effect of bottom friction is particularly noticeable in these sections. The density isolines, which are normally horizontal, turn downward as they come within 20 to 50 metres of a shoaling bottom, the distance depending on the nature of the currents. If the bottom rises steeply the area of mixing is small and there is much less effect on the isolines. Thus in the Grand Manan to Digby section the lines turn downward to the gradually shelving bottom on the Digby side, but meet the steep bottom slope at Grand Manan without change. This condition is reversed in the southernmost section, where the bottom off Brier island slopes steeply while on the Maine side the bottom rises gradually above 100 metres. Near the head of the bay of Fundy between Found head and Margaretville the average depth is only 50 metres, and the tidal currents are very strong, with the result that the density isolines are actually vertical. Why the water on the New Brunswick side should be lighter than on the Nova Scotian side is not clear, for there is considerably more fresh water running into Minas basin than into Chignecto bay (see fig. 3). Possibly the light water from Minas basin has already been driven westward above this section. In such homogeneous water wind effects must also

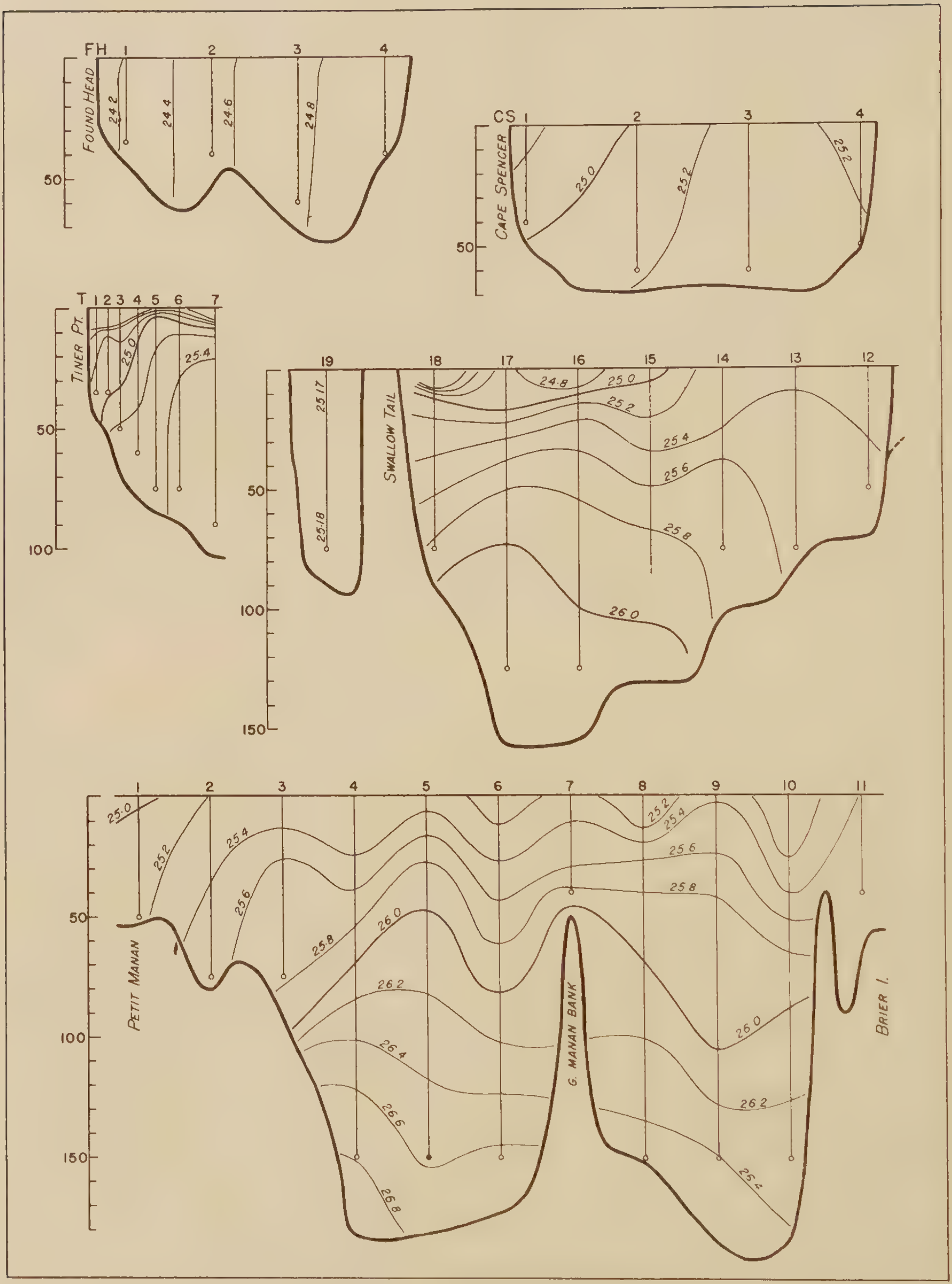

FIGURE 15. Transverse σ_t (density) sections, bay of Fundy, June 15-18, 1932.

be important, but there are not enough data at hand to study this interesting region in any detail.

The effect on the isolines of a gradually shoaling bottom is further demonstrated by the longitudinal sections of the bay in figure 16. The progressive lightening of the water at any level as the head of the bay is approached is slightly modified near the surface by the Saint John outflow and by the cyclonic circulation around station 17 (approximately the same as station S3; see sect. 5). This progressive lightening shown by the slope of the surfaces of equal density is indicative of the fundamental movement of light water from the bay of Fundy towards the gulf of Maine. Since the bay contains bottom water of high salinity, this must necessarily come from the gulf of Maine. During the winter months there is a minimum amount of fresh water flowing into the bay and owing to the low stability and strong winds there is free interchange at all depths between the bay and the neighbouring gulf. This winter water might remain at the bottom of the bay during the spring and summer, gradually getting warmer and fresher by dilution from above. From the observations, however, it can be seen that the deep water, for example at 100 metres at stations S3 or 17, gets progressively salter from $32.5^0/_{00}$ at the end of April to $33.2^0/_{00}$ early in September. This shows that there is a steady inflow of salt deep water from the gulf of Maine which more than compensates for the dilution from vertical mixing. Reference

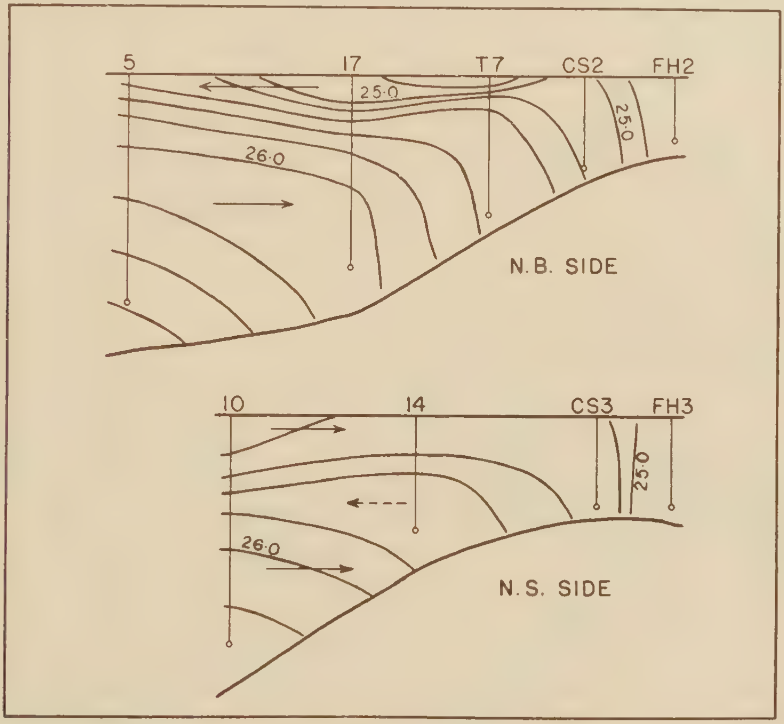

FIGURE 16. Longitudinal σ_t (density) sections, bay of Fundy, June 15-18, 1932.

to figure 16 along with the following explanation should make the mechanism of interchange at different levels clear.

There are two systems of movements which may occur in a mixing zone such as the bay of Fundy. If normally stratified waters are mixed by tidal stirring, as on the Nova Scotian side of the bay, there will be an inflow of light surface water, an outflow of intermediate mixed water and an inflow of bottom water. If, however, there is a considerable addition of fresh water at the mixing zone, as on the New Brunswick side of the bay, there will be only two movements, a surface outflow and a bottom inflow. Both these systems of movements resulting from the mixing of stratified waters have been produced experimentally and described by Hachey (1934B). In figure 16 the directions of flow in each section are indicated by the arrows. In the bay of Fundy the bottom water right across the deep channel moves inward, but the surface water runs outward near Grand Manan and inward near Nova Scotia. The existence of the inward current along the Nova Scotian side of the bay has been proved by many drift bottle returns as well as by Mavor's analysis of Dawson's current measurements, and its explanation lies in the different mixing conditions on either side of the bay. The mixed water produced on the Nova Scotian side must flow either outward to the gulf of Maine as a sub-surface current or across to the New Brunswick side to augment the supply of bottom water which is steadily being consumed by the Saint John mixing mechanism. The former does not seem likely, as there has never been any evidence for it, and presumably its effect would have been noticed in Dawson's current measurements. Between Grand Manan

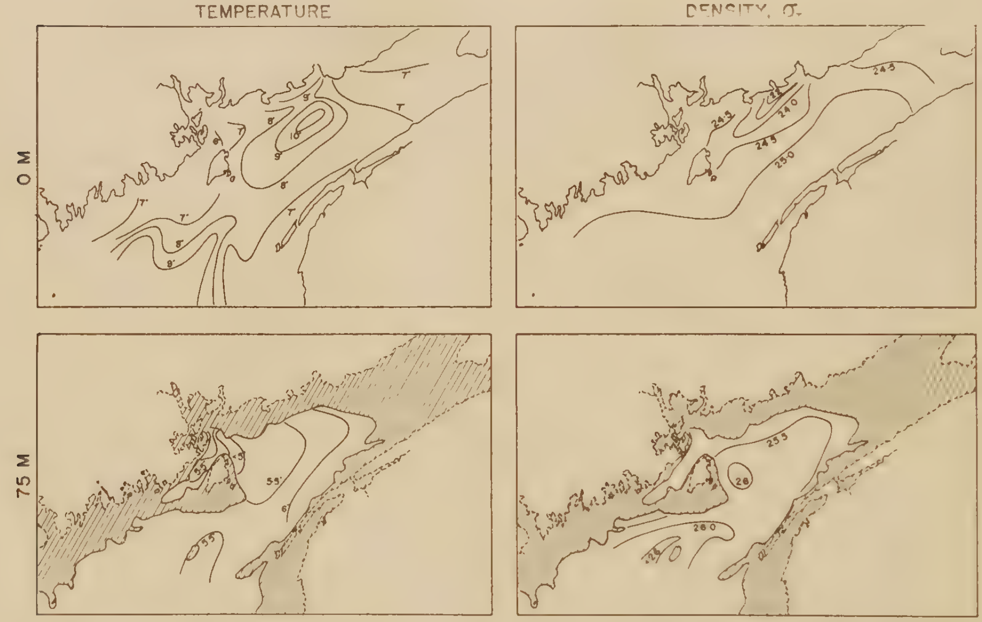

FIGURE 17. Temperature and density at 0 and 75 metres, bay of Fundy, June 15-18, 1932.

and Saint John the bottom water is gradually lightened by vertical mixing, so that off Tiner point the upper boundary of the relatively homogeneous bottom water is the $\sigma_t = 25.4$ surface, which occurs at a depth of 20 metres about 10 miles (18 km.) off shore. It seems highly probable that the mixed water of density $\sigma_t = 25.3 - 25.5$ which is found from surface to bottom off Digby (sta. 12, fig. 15) and as far north as Port Lorne (sta. CS3, figs. 15, 16) moves across the bay towards Saint John, merging with the deep water which has come in more directly on the New Brunswick side. Thus in figure 16 the juxtaposition of the two systems of mixing modifies the one in the Nova Scotian section and the flow of the intermediate mixed water is not outward as indicated by the broken arrow but at right angles to the section and across to the New Brunswick side. It is easily seen that this combination of the two mixing systems offers much less

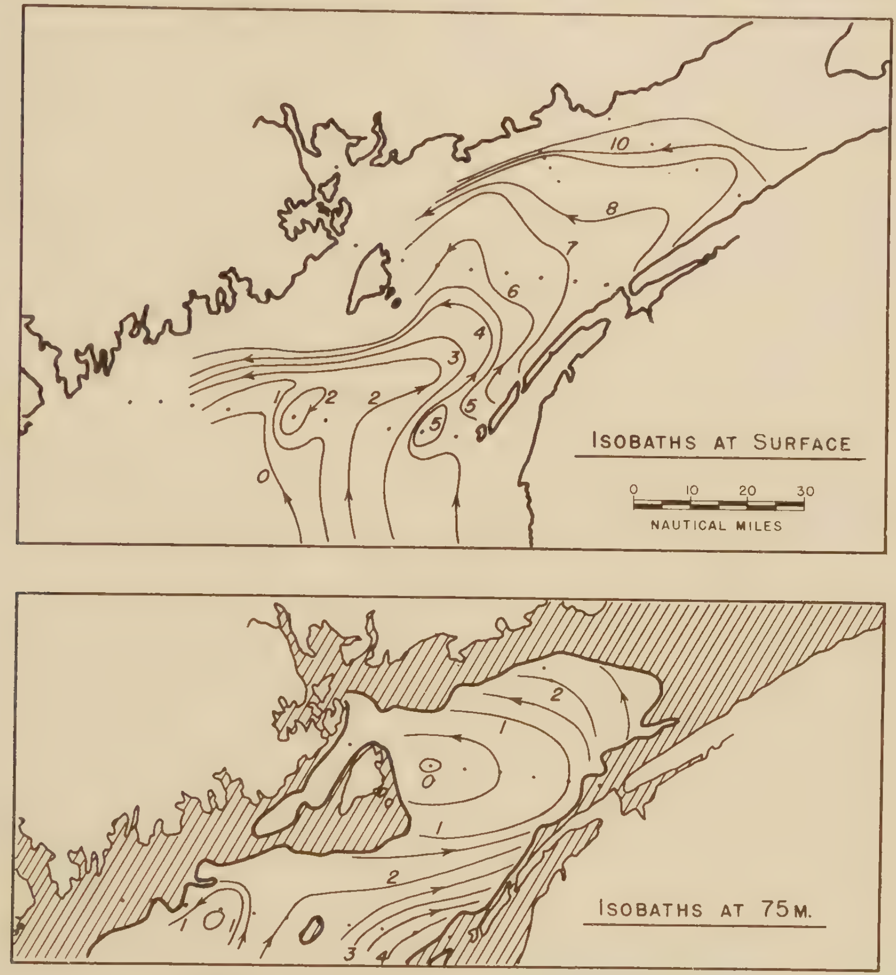

FIGURE 18. Current fields in June as shown by dynamic isobaths. Figures show dynamic centimetres above the lowest point in each isobaric surface. Current velocity in knots is approximately equal to the traverse gradient in dyn. cm./mile.

resistance to flow, since there is no longer a layer moving in the opposite direction to the water above and below it. Nevertheless there will still be an outward pressure at the intermediate depths on the Scotian side, so that the inflow will still be greatest at the surface and bottom but negligible at intermediate depths. Since the heavier bottom water moves inward on both sides the density isolines near the bottom will slope downward from the Maine or New Brunswick side towards the Scotian side, as for example the $\sigma_t = 26.4$ line in figure 15.

Further evidence of the residual movements in the bay of Fundy is given by the dynamic topographic charts in figure 18. These charts are based on the same data as the sections in figure 15, but they must not be considered as accurate representations of the currents, since the method of calculating the dynamic heights of the stations is inherently inapplicable to shallow waters with strong bottom currents. Corrections have been made throughout for unequal depths of adjacent stations, but often the correction was as great as the difference in dynamic height to which it was applied. Furthermore, the distance between the sections allows great freedom in sketching in the isobaths and using the same calculated heights at the stations one may draw very different sets of isobaths. Nevertheless the salient features of the current system are indicated by the isobaths. The velocity in knots is approximately equal to the reciprocal of the distance in nautical miles between successive isobaths. As the stations in the two lower sections are six miles (11 km.) apart it is easy to estimate the current velocity in any region as indicated by the isobaths. The most prominent surface currents are the Saint John current, the westerly outflow towards the Maine coast, and the inflow on the Nova Scotian side. The two closed isobaths in the southernmost section are due to the effect of the bottom configuration of Grand Manan bank and a submarine ridge off Brier island. As has already been explained (sect. 6) they represent failure of the calculations for dynamic height rather than the actual lines of flow of the water. At 75 metres, the water seems to set easterly in the lower portion of the bay and westerly in the upper portion. The lack of continuity of the isobaths at 75 metres in figure 18 is easily understood by reference to figures 15 and 16. The rather rapid easterly flow towards the Scotian coast consists of water which is heavier than $\sigma_t = 25.8$ between Grand Manan bank and Brier island. It is drawn towards the coast because it is being consumed there by vertical mixing, and as it approaches the coast it becomes lighter because of more rapid dilution with water from above. Further up the bay (see fig. 15, stations 13 and 14) the water at the 75 metre level has been diluted to a density of about 25.6, so that here it forms the lower boundary of the layer of mixed water of density $25.3 - 25.7$ which moves across to the New Brunswick side. At stations 12, 13, and 14 this layer occupies the whole depth of water down to 75 metres, so that its velocity at any one level is insignificant. On the New Brunswick side the 75 metre isobaths again run into the coast because the bottom water is being drawn upward into the Saint John outflow. Such movements illustrate the importance of vertical transport in coastal waters and the consequent necessity for drawing vertical sections.

The variation in the stability of the surface layer from month to month is particularly interesting and is important for the production of phytoplankton.

According to Braarud an increase in stability in the bay of Fundy has a beneficial effect on the production of phytoplankton. Owing to the frequency of cloudy days and the turbidity of the water the thickness of the layer in which light is sufficient for good growth is only about 20 metres, and the effect of vertical mixing is to deplete the plant stock by removing it from the thin productive layer. Figure 19 shows the areas of greatest stability of the upper 25 metres for the months of May, June, August and September. There appears to be high stability in May as a result of the fresh water from the spring freshets, but it decreases to a minimum in June as the light surface water is dissipated. In August the rising temperature of the surface water again increases the stability, until in September decreasing air temperature and strong winds combine to reduce it once more. It probably does not increase again until the following spring. As there are no available data on the monthly variation in stability over the bay from year to year an attempt has been made to follow this by using the differences in temperature at 0 and 20 metres at the regular Atlantic Biological Station no. 5, in the Outer Quoddy region. It would seem that the time of occurrence of the stability minimum must depend on the time and volume of the spring freshets and also on the amount of sunshine in the summer months. It may be still further complicated by variations in the rate of horizontal interchange due to wind action. The tendency seems to be for years with maximum freshets in April (1921, 1927) to have a stability minimum in July or early August, while maximum freshets in May (1926, 1928, 1930) are followed by an earlier stability

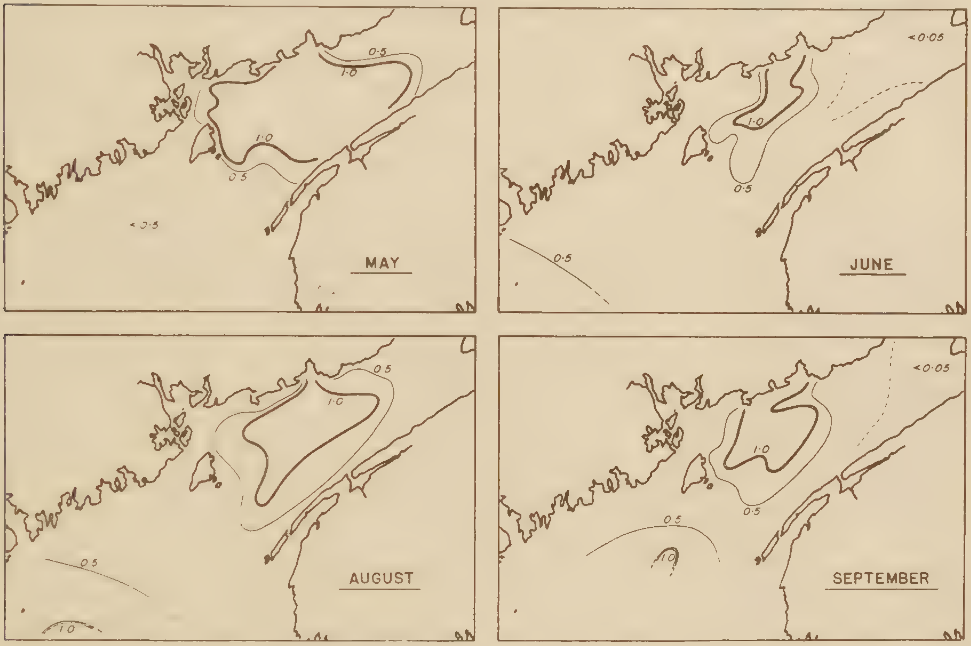

FIGURE 19. Stability of surface layer as measured by the difference in σ_t at 25 metres and 0 metres

minimum in June or early July. Also in 1924 when the Saint John outflow was unusually concentrated in May, there was only a slight decrease in stability in June. These results are based on data which are too isolated to be conclusive and they are presented only in view of their possible importance.

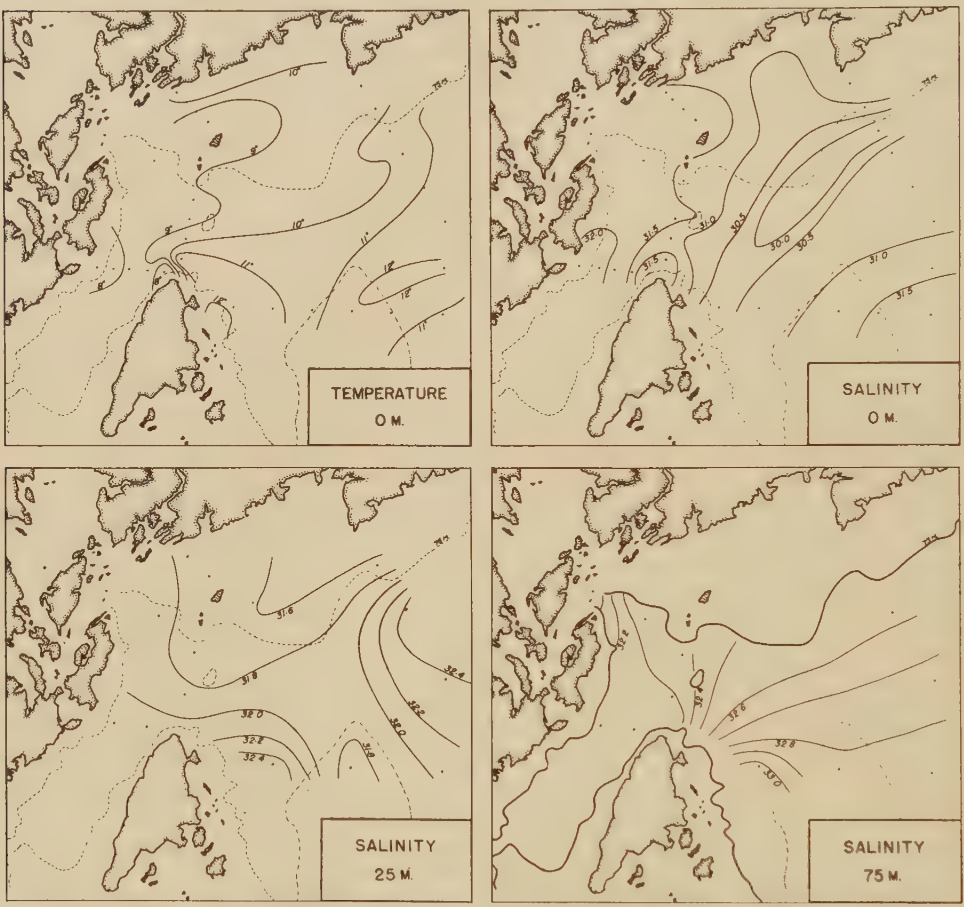

FIGURE 20. Salinity and temperature, Outer Quoddy region, July 7, 1932.

8. SUMMER CONDITIONS IN THE QUODDY REGION AND THE ADJACENT PART OF THE BAY

The interchange of water between the Quoddy region and the neighbouring parts of the bay is so variable that the observations obtained have not been sufficient to show the movements clearly. In such a restricted region the supply of fresh water, the tides and the winds, not only at the time but during the previous week, will all modify the resultant water movements. In particular, owing to the relation of the region to the Saint John current, the effect of the tide is to remove certain waters from the region on the flood while the ebb introduces new waters from outside. Radical changes in distribution will occur in six hours and the only way of getting a detailed picture of the movements is to make simultaneous observations from as many boats as possible, and to repeat these observations under various conditions of tide, wind and season. Observations

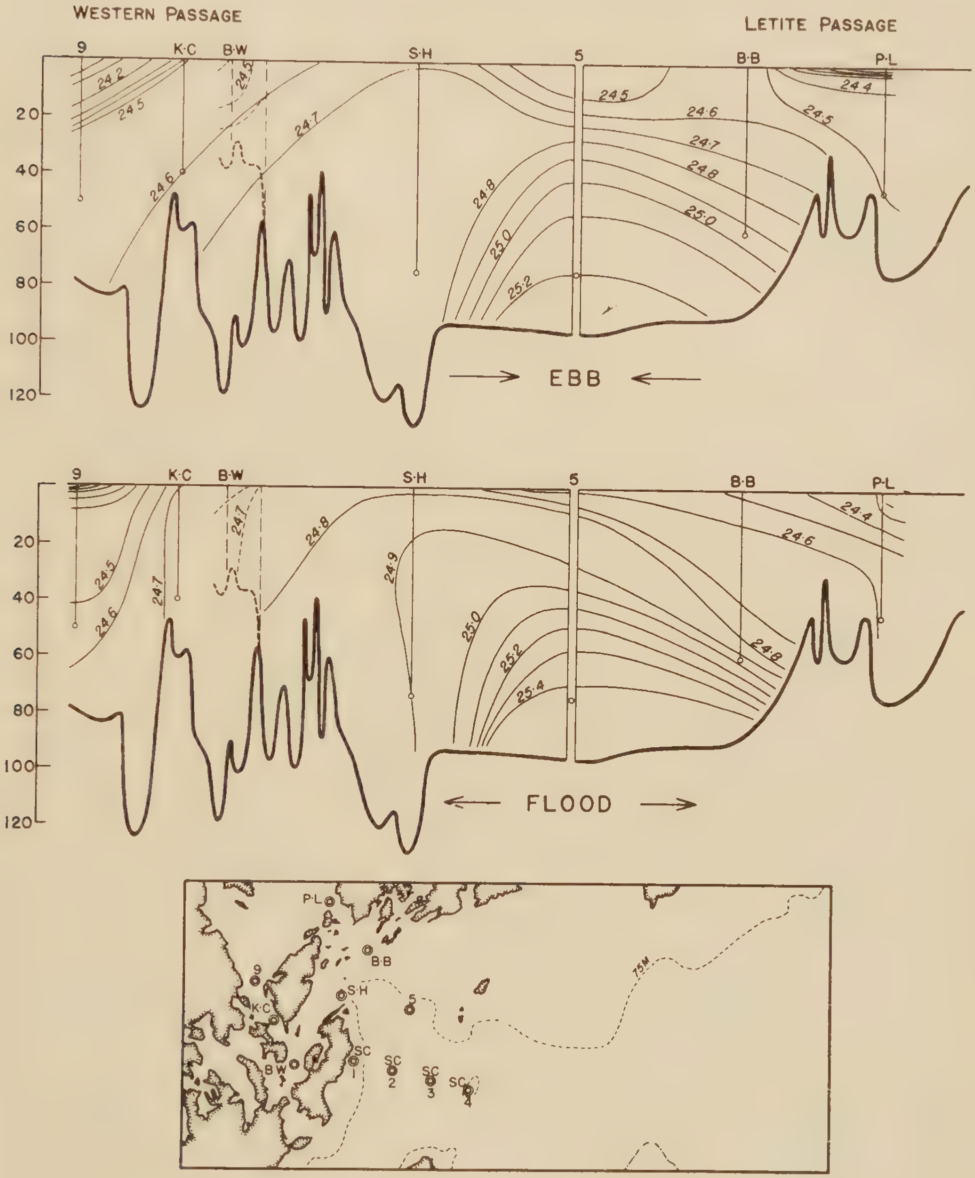

FIGURE 21. σ_t (density) in passages, ebb and flood, July 26, with key to stations.

taken from a single boat, however frequently, can give little information as to movements. On August 5, 1931, a surface temperature survey was carried out by four boats simultaneously, both at high water and at low water (fig. 22). On July 7, 1932, using only two boats, a complete hydrographic series was run at low water. Figure 20 shows the distribution of salinity at 0, 25 and 75 metres and also the surface temperatures. The remaining data may be found in the tables. The question of greatest interest in this region is the effect of the Quoddy mixing mechanism and the part which it plays in determining the circulation of the Outer Quoddy region. Figure 21 shows the simultaneous values of σ_t in the two passages from Passamaquoddy bay out to station 5, during the last half of each

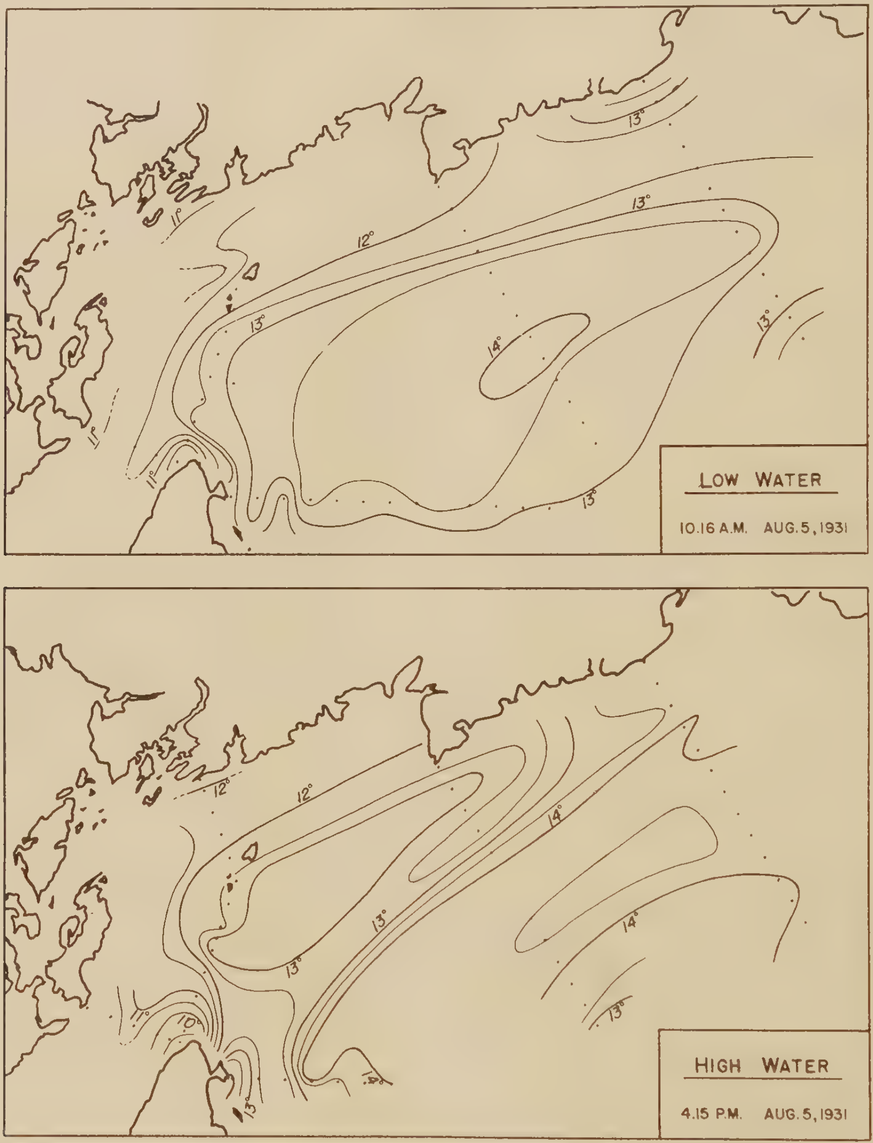

FIGURE 22. Surface temperature off the Quoddy region, at low water and high water, August 5, 1931.

tidal flow on July 26. These sets of observations present a fairly complete picture of conditions, but it is difficult to deduce from them the details of the water movements. Certainly the mixing mechanism of the passages does not appear to dominate conditions in the Outer Quoddy region. In figure 21 the flood tide water entering the passage between Spruce island and Head harbour (station S-H) is not the stratified water from station 5, only about four miles (7.4 km.) away, but homogeneous water which probably emerged from the passages on the previous ebb tide. It appears that a large fraction of the water which comes out of the passages on the ebb tide returns into them on the succeeding flood and that the residual outflow of mixed water over a complete tidal interval is quite small. Nevertheless since there is a considerable drainage of fresh water into Passamaquoddy bay there will be an outflow of mixed water from the passages in the upper layers and a consumption of heavier water from below. The source of this heavier water and the subsequent path of the outflow are of great interest, but they are both somewhat uncertain owing to the smallness of the quantities involved in comparison with the tidal transport.

The following is the writer's interpretation of the July 7 survey. The most prominent surface water (see fig. 20) consists of a wide band of light fresh water outside the 75 metre contour, sweeping past Lepreau towards Grand Manan. ($S < 31^0/_{00}$, $\sigma_t < 24.0$, $t > 10°$). This band is bordered by the heavier salter water in the middle of the bay and by similar water ($S > 31.5^0/_{00}$, $\sigma_t > 24.0$, $t < 9°$) in the Outer Quoddy region. The latter is very sensitive to wind and tidal conditions and seems to play no definite role in the mixing mechanism, which draws its light water from the inner bays. At a depth of from 20 to 50 metres the mixed product of the mechanism flows first southward and then eastward, the boundaries of its path being indicated by the $31.8^0/_{00}$ and $32.0^0/_{00}$ isohalines at 25 metres (see fig. 20). This deduction is based on the argument that vertical mixing is not very effective at this depth since it is above the region of influence of bottom friction and below the depth of normal wind stirring. The density isolines or the isohalines will therefore run in the direction in which the water moves. Of course the isoline at a certain depth only marks the boundary of the water at that depth and it may flow at right angles to the isoline by rising to a higher level. But in that case the layer becomes thin and soon loses its identity. At or below 75 metres, on the contrary, the water is subject to vertical mixing and will become lighter as it progresses, so that the direction of flow will be at right angles to the isolines, except where the depth is much greater than 75 metres. The 75 metre section in figure 20 shows that the heaviest or most saline water moves from the deepest part of the bay towards the coastal slope, a portion entering the Outer Quoddy region and moving towards the passages. Some of this deep water at the passages may also originate in the bay as water of the same density and salinity, but at smaller depths. The part played by Grand Manan channel remains obscure, but since it is so nearly homogeneous any interchange with the Quoddy region is probably determined by combinations of wind and tide.

The dynamic heights of the water off Lepreau and at sta. 5 were given for May. Dynamic heights obtained later in the summer are: July 7, at L4, 7314.94 cm., and at sta. 5, 7317.02; Sept. 4, at L3, 7316.78 cm., at L4, 7315.93

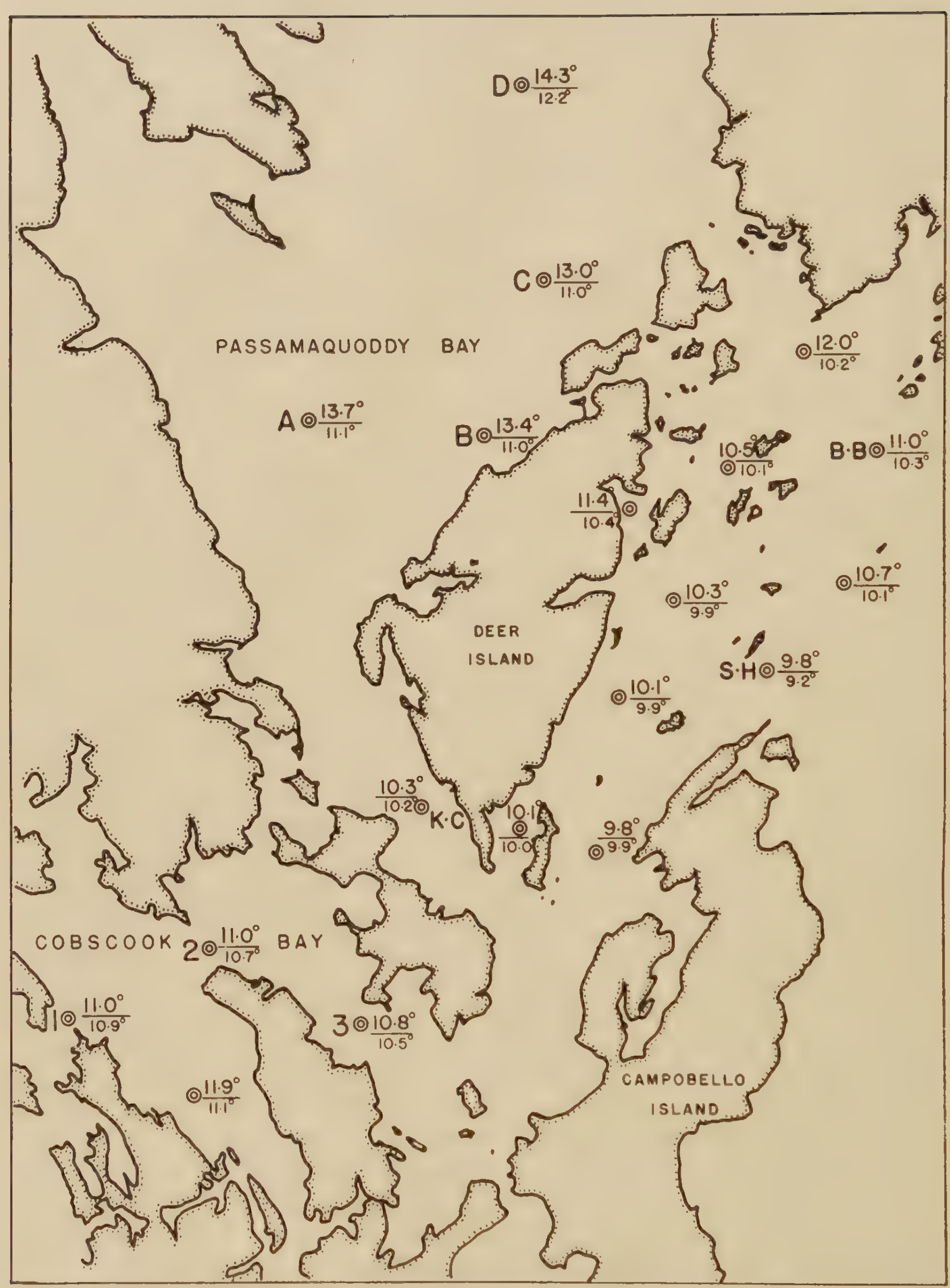

FIGURE 23. Temperature at surface (upper figures) and 5 metres (lower figures), Inner Quoddy region, high water, Aug. 5, 1932.

cm.; and Sept. 12 at sta. 5, 7317.70 cm. Thus in July and September, as well as in May, the water at sta. 5 is dynamically higher than at L4. This means that throughout the summer the average density at sta. 5 is such that gravity forces are called into play which prevent the surface Saint John current from entering the region. An inspection of figure 19 shows that throughout the summer the stable surface layer includes the Saint John current and excludes the Quoddy region. Consequently a greater absorption of heat takes place at sta. 5 than beneath the stable insulating layer, so that on July 7 the average temperature of the water to a depth of 75 metres is 6.9° at L4 and 7.4° at sta. 5, while in September the difference is still greater, 9.7° at L4 and 10.8° at sta. 5. This difference in absorption of heat tends to make the water at sta. 5 lighter. If the mixing in the region were reduced the surface water would become more stable and the average temperature less. This would mean a decrease in the dynamic height

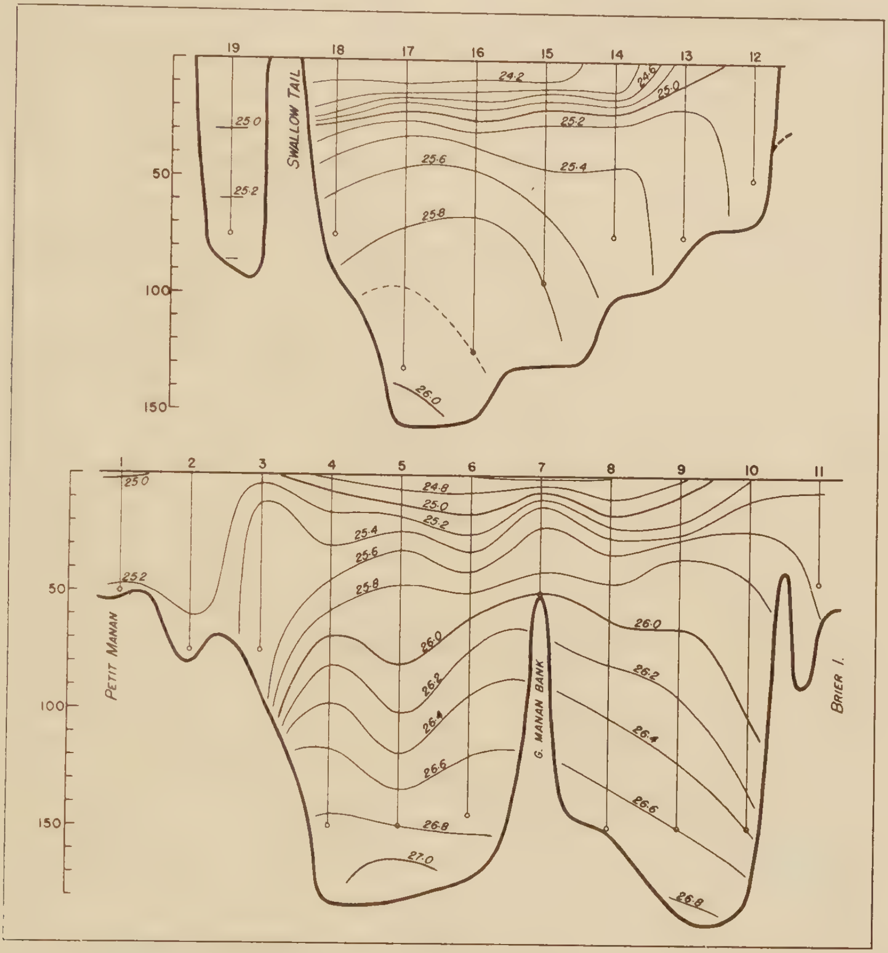

FIGURE 24. σ_t (density) sections, bay of Fundy, September 4-7, 1932.

and therefore less resistance to the Saint John current, which might then enter the Quoddy region.

On August 5 at high water a rapid survey was made of the waters in the passages and in Passamaquoddy bay, using two boats. The temperatures of the surface layer at 0 and 5 metres are shown in figure 23. The stations in Cobscook bay were taken at the same stage of tide on the following day, so that

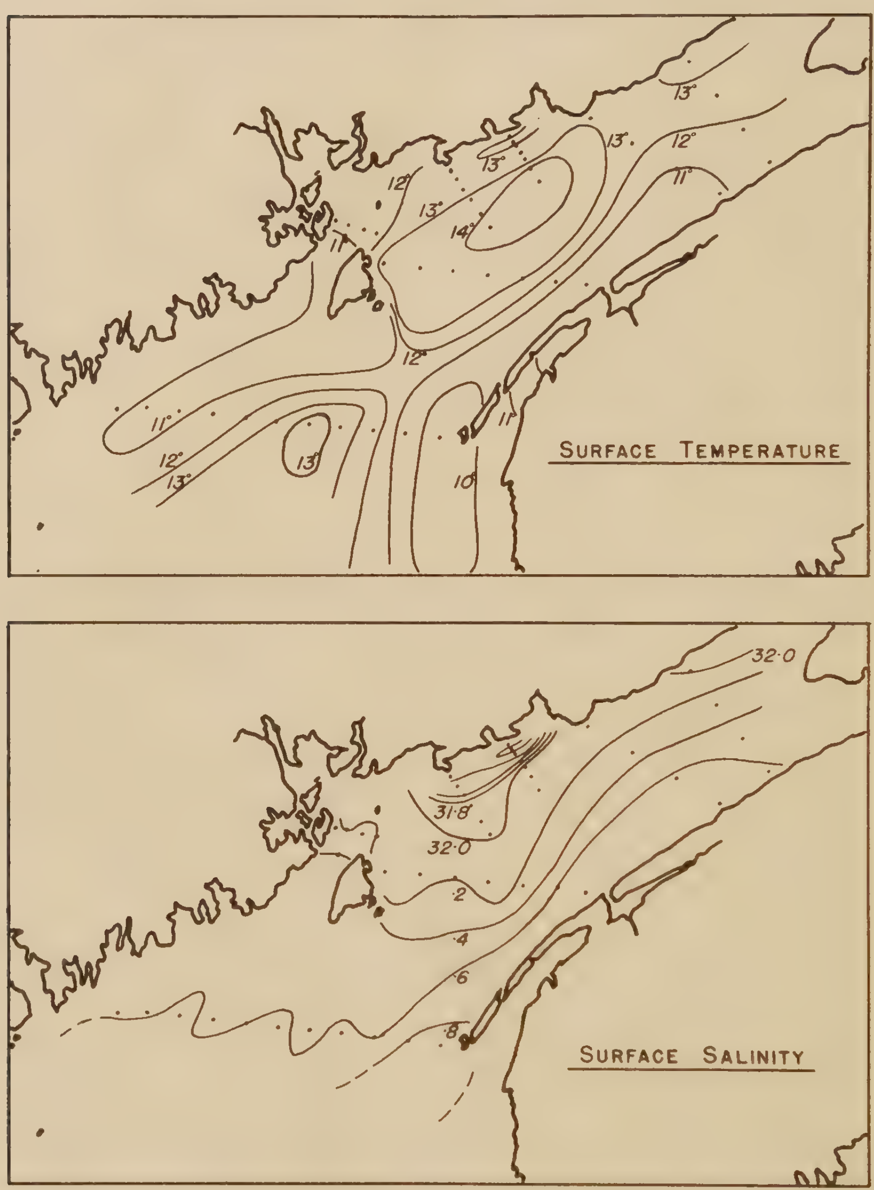

FIGURE 25. Surface temperature and salinity, September 3-7, 1932.

the whole set of observations may be regarded as simultaneous. The low surface temperature of 9.8° in the passages is indicative of the unusual conditions which exist in this region.

9. SEPTEMBER HYDROGRAPHIC SURVEY OF BAY OF FUNDY

Between September 3 and 8 the June survey was repeated in order to observe the seasonal progress. On the whole there was remarkably little change in the distribution and only a slight decrease in the actual values of the densities, since the increase in temperature was nearly balanced by the increase in salinity. Figure 24 shows the density distribution for the two main sections across the bay and these should be compared with the same sections taken in June (fig. 15). Figure 25 shows the surface distribution of salinity and temperature. As before the warmest water occupies a pool in the middle of the bay while the warm gulf of Maine water is found as far north as Grand Manan bank. The maximum temperature is nearly 15° as compared with 10° in June. The light surface water is more widespread than in June, since it is due to high temperature rather than to the low salinity of the Saint John outflow. A section taken from Schooner cove on Campobello island across the Outer Quoddy region to the Wolves bank at low water is shown in figure 26. The distribution of the isolines suggests an outflow from the passages moving south at an average depth of 50 metres. Sim-

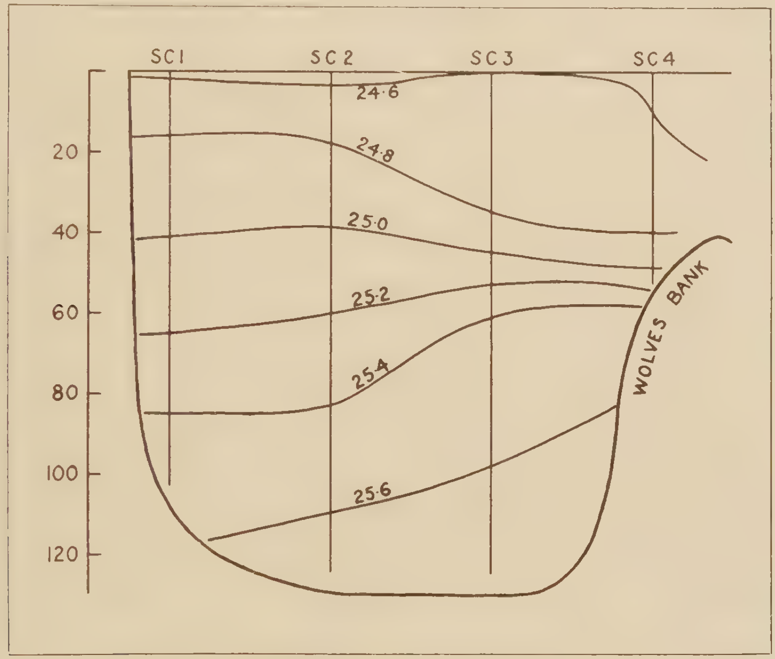

FIGURE 26. σ_t (density) section, Campobello island to Wolves bank, September 7, 1932. For key to stations, see figure 21.

ultaneous sections were taken across the south end of Grand Manan channel and from Machias bay to Seal island, in the region to the south of the channel, on September 29 after a few days of strong winds. Both sections seemed to indicate a surface current moving southward from the channel.

The observations given in this paper should be supplemented by those of Mavor, whose work was carried out in the latter part of the summer. Owing to lack of space it is impossible to give any further discussion of the results obtained from the September survey.

10. SUMMARY

Winter temperatures in Passamaquoddy bay are lower than in the bay of Fundy but not as low as in bays further south, such as Cape Cod bay. In the Outer Quoddy region the vertical distribution of temperature is determined by the fresh water discharge into the neighbouring bays. From November to February the coldest water is at the surface, but around March 1 it is found as a sub-surface layer at 25 metres. In 1932 this distribution was maintained until late April. During March and early April a rise in temperature in the Fundy deep indicates an inflow of warmer water from the gulf of Maine.

On the arrival of the spring freshets at Saint John a stratified surface layer flows over the homogeneous Fundy water towards Grand Manan. In early May water with a temperature between 1° and 2° is found beneath this insulating layer, and this water is then the coldest throughout the bay of Fundy or the gulf of Maine. The decreased absorption of heat beneath this layer sets up a density distribution which keeps the Saint John current out of the Quoddy region. In the Outer Quoddy region maximum spring tides at this season increase the salinity at all depths and decrease stratification. The drift through Grand Manan channel is into the region, but small. The outflow from the Quoddy region as a whole is also small. Further observations in May show the existence of a central eddy off Swallow Tail where the Saint John current runs out over water of increasing depth (see Part I, sect. 5). Mixing by the Manan shoals is of local importance, but as in the case of most banks and shoals the mixed water remains in the mixing region.

A general June survey of the bay of Fundy shows that the most prominent surface movements are the Saint John current, the westerly Fundy outflow and an inflow on the Scotian side. The Fundy outflow originates to the east of Grand Manan, and flows westerly in a thick surface layer towards the Maine coast, along the border of a body of homogeneous coastal water which extends from Grand Manan channel to Petit Manan. The very slow northeasterly drift in this homogeneous water may be due to the prevailing SW winds. On both sides of the bay of Fundy below 100 metres there is an inflow of bottom water from the gulf of Maine which more than compensates for dilution from vertical mixing. Except for modifications by the Saint John current and the central eddy, the water at any level gets progressively lighter as the head of the bay is approached. The dominant feature of the bay is the turbulence within the layer of frictional influence of the bottom, which is from 20 to 50 metres high. The stability of the upper 25 metre layer has a June minimum with maxima in May and August, decreasing again in September and remaining very low until the following spring. The circulation in the Outer Quoddy region is rather indeterminate and the outflow from the Quoddy passages does not appear to produce any dominant effect. Indications are that it travels first southward and then eastward at a depth of from 20 to 50 metres, passing between the Wolves bank and Grand Manan. Below this outflow there is a slow inflow of heavy water which is gradually diluted by turbulence as it moves from the Fundy deep into the Quoddy region.

In September the density distribution and the water movements in the bay are practically the same as in June, though the temperatures are of course much higher.

Hachey (1934, A) has attempted to use vertical temperature gradients as an indicator of the replacement of bay of Fundy waters, using the differences beween the annual ranges of temperature at surface and 20 metres, and at 20 and 90 metres. Observations were made once each month at a single station in the Outer Quoddy region (sta. 5). However, the annual temperature range as determined from such occasional observations may easily have an error of plus or minus one degree, and, as the difference of the ranges at two levels is on the average only about one degree, it is clear that they cannot be calculated from such inadequate data. In addition the station chosen is certainly not representative of the bay of Fundy.

In a subsequent paper, Hachey (1935) states that the extent of the renewal of the bay of Fundy water "will depend upon the amount of the salter bay of Fundy water that the reversing falls consumes". It will be shown (Part III, sect. 6) that, while the rate of inflow of the bottom water does depend largely on the discharge of the Saint John river, the mixing in the reversing falls is quite unimportant compared with the subsequent mixing outside the river estuary. Hachey's conclusion that the inflow "can be represented by a stream 20 miles in width, 20 fathoms in depth and with a velocity of 5 miles per day", a rate which "corresponds with the known circulation from drift bottle investigations", is very misleading since it infers that the inflow is on the surface. His calculation is based exclusively on surface salinities, but no such calculation can be applicable to the bay of Fundy where the inflow consists mostly of heavy bottom water.

PART III. GENERAL CONCLUSIONS

A summary of the conditions and movements observed in the bay of Fundy has been given in the final section of Part II. We shall now proceed to discuss certain hydrological phenomena which have been studied in connection with the bay of Fundy, but which are of quite general interest.

1. Estuarial Mixing

In connection with a study of the Saint John river outflow it has been found that the estuarial features at Saint John are somewhat different from usual and lead to unusual hydrographic conditions in the neighbouring region. In such estuaries as Penobscot bay, Maine, or the Severn estuary in England, vertical mixing is effective and though there is little difference in density from top to bottom at any one station, the density increases as we approach the open sea. The change from the estuary to the sea is a gradual one, both with regard to depth and to the physical properties of the water. At Saint John, however, the estuary is short, consisting only of the harbour which is very shallow except for a dredged channel. The bottom of the open bay of Fundy then drops away with a gradient of about 10 metres per mile (1.8 km.) down to 75 metres. Thus the river water, instead of gradually losing its identity as it travels down a long estuary, flows directly out to sea as a strongly stratified layer, about 10 metres thick. It retains its lower boundary as far as Grand Manan island, a distance of 40 miles (74 km.). The resistance to vertical mixing is remarkably great and the explanation seems to be as follows. Vertical mixing is effected by the transport of water particles from one layer into another. This is accomplished by the eddies produced at the interface between two layers moving at different velocities. Quantitatively the energy available to effect vertical mixing is proportional to the square of the vertical velocity gradient. The resistive force which prevents mixing is a gravity force, and the work done against it is proportional to the density gradient. Hence the continued existence of a strongly stratified surface layer above homogeneous water is dependent on the relative values of the density gradient and the velocity gradient. Now in an estuary or a shallow bay bottom friction produces a strong vertical velocity gradient and a considerable fraction of the kinetic energy of the water goes into eddy motion. The energy in these eddies is then used up by destroying the vertical density gradient. But the conditions at Saint John are such that a strongly stratified surface layer, practically filling the shallow harbour, flows out over deep homogeneous water. With the increase of depth the gradient of velocity becomes small, although the actual tidal velocities are high. So the stratified surface layer is not destroyed in spite of the rapid movements of the tidal streams. Of course the volume of the river outflow is also important for the maintenance of the density gradient in the surface layers as they spread over the Fundy water. The addition of salter water in the mixing mechanism increases the total outflow, though it decreases the density gradient, and it is questionable whether the reversing falls increase or decrease the extent to which the Saint John waters are noticeable in the surface layers. Another consequence of the balance between the production of eddy energy and the work done in layer destruction is that the stratified surface layer will rapidly disappear as such if it runs over a region of shallow water where the gradient of velocity is increased. It should therefore be borne in mind that the continuation of a surface layer over deep water and its disappearance over shallow water does not exclude the possibility that a considerable amount of the surface water may have flowed over the shallow region.

2. The Formation and Maintenance of Homogeneous Water

It is a matter of common observation that currents flow clockwise around a bank, and that the water above the bank is almost homogeneous, as for example in the case of Georges bank (see Bigelow, figs 186 and 203). We shall establish the general principle that any area which contains homogeneous water, however this may be formed, will be conspicuously lacking in permanent residual currents. The only internal force which can maintain a current is a gravity force due to density distribution, measured quantitatively by the number of solenoids. Since the retarding force of friction exists everywhere, a current can only continue where there are solenoids to propel it and overcome friction. While there are few, if any, solenoids in homogeneous water there will be a great number around its periphery where the isosteric surfaces must slope if there is a transition from homogeneous to stratified water. Consequently we will find a gravity propelled current only at the periphery. On the other hand variable wind currents will occur in the homogeneous water much more easily than elsewhere since there are no gravity forces to oppose such currents. Bodies of water such as we have been discussing are found close to a coast line which is on the right of a current flowing parallel to the coast. The homogeneity is produced by continual turbulence in the tidal streams in shoal water, either close to shore or over a large bank. Examples are Georges bank, the head of the bay of Fundy, and Grand Manan channel with the shoal region to the south and southeast of it.

If a homogeneous region is to be permanent it must continually receive or produce sufficient light water to keep its density lower than the mean density of an equal depth of water just beyond it. This is simply the condition that there shall be an outward gravity force on the surface water to balance the inward dynamic force of the peripheral current. For otherwise the current and the peripheral stratified water would move in, and homogeneity would be destroyed. Georges bank at once furnishes examples of both these cases. At the northwestern edge of the bank, near cape Cod, the hydrostatic forces drive light surface water onto the bank too rapidly for homogeneous water to be formed and we find stratified water over the bank. At the eastern edge the water above the bank is homogeneous and lighter than an equal depth of the water just off the bank, so that there is an outward hydrostatic force to keep the periphereal current away from the bank. Furthermore this condition is maintained because there is a supply of light water available to the mixing region from the east and north. On the other hand a bank which has no local supply of light water will be covered by water which is heavier than the surrounding water, since the isosteric surfaces are rasied by the momentum of the water which is forced up the slopes of the bank. There will be no peripheral current to retain the water above the bank, and so it will not remain long enough to become homogeneous. Such a case is illustrated by Grand Manan bank (see Density sect., fig. 15), where the isosteric layers are raised above the bank, but not destroyed. The stability of the water above the bank may even be increased, as it was on September 4. The dynamic isobaths at the surface for such a region will, of course, show a depression above the bank, and this is not to be interpreted as due to a cirulatory surface current, but to the upwelling on the slopes of the bank.

Another important factor which helps to lighten the homogeneous water is the greater absorption of heat. In the summer stratified layers at the surface prevent transfer of heat downwards, but the free vertical motion in homogeneous water facilitates it. The average temperature of a vertical column above the bank is considerably higher than that of an equal column off the bank. For example, a station on Georges bank in June varies from 10° at the surface to 9.7° at 60 metres while a station in the channel to the northeast of the bank averages just over 6° for the same depth ("Atlantis" stations 1673 and 1658). Furthermore, the average salinity at the bank station is higher than at the channel station, but its higher temperature is sufficient to keep it lighter. This differential absorption of heat is important, but it is essentially a secondary factor since it only comes into action when the water has been maintained in a homogeneous state for some time. However, it may be that the selective freshening of the mixed water in the spring lightens it sufficiently to prevent the inroads of the periphereal currents only just long enough for the selective heating to take the major role in lightening the mixed water.

3. THE EFFECT OF A SHOALING BOTTOM ON TIDAL WATERS

The effects of bottom friction on coastal waters are most easily understood by resolving the complex motion of the water into its two major components, the oscillatory tidal motion and the residual current or drift. In a purely oscillatory tidal motion, turbulence spreads upward through the water, breaking down stratification, until finally the whole vertical column is rendered homogeneous. Since on the whole the water does not move away from the source of turbulence the effect must be cumulative. At each station in the region considered the water will finally be homogeneous from surface to bottom. However, the rates of interchange vertically and horizontally are of the same order while the vertical depth is only a very small fraction of the horizontal, so that mixing may be complete vertically while the density changes considerably from station to station. Now consider the effect of a residual current which we may assume to be on the surface, since the horizontal distribution of fresh water takes place on the surface. As soon as horizontal motion occurs the effects of mixing at one particular place are no longer cumulative and will only extend to a height above bottom determined by the degree of turbulence and by the rate of removal of the mixed water. The water will then become stratified in the upper layers, and will tend to become homogeneous only within a certain distance from the bottom. This distance depends both on the degree of turbulence, and on the rate of removal of the products of mixing. Where we have a shoaling bottom the height of influence will reach into higher and lighter layers as the depth becomes less, so that in succession the isolines will turn downward, and while the water for some distance above bottom will be homogeneous at each station it will become lighter as we move to a shallower station. If we refer to figures 15 and 16 and examine the behaviour of the density isolines in relation to the bottom we see that the lines turn downward as they come within 20 to 50 metres of a gradually shoaling bottom, but are unaffected when they meet a steep bottom slope. When the bottom rises steeply the volume of water within which turbulence occurs is small and probably no individual portion of water remains in this region for more than a fraction of its tidal path. The distribution of the density isolines in figures 15 and 16 has been discussed in more detail in Part II, section 7.

4. CURRENT SYSTEMS PRODUCED BY TIDAL MIXING

If stratified waters are mixed by tidal stirring the mixed water moves away from the region at an intermediate depth while surface and bottom waters flow in towards the region. When fresh water is supplied directly to the mixing region the current system is reduced to a surface outflow and a bottom inflow. In the case of the bay of Fundy both cases occur in adjacent regions and the resulting system is still further modified. The reader is referred to Part II, sect. 7, for a complete discussion of the resulting current system. In particular it is to be noted that the juxtaposition of the two systems is not peculiar to the bay of Fundy but may occur wherever the fresh water inflow to a bay or gulf is concentrated along one side.

5. QUANTITATIVE DETERMINATION OF THE EFFECT OF MIXING, WITH EXAMPLES FROM THE BAY OF FUNDY

Since the term mixing is used for various effects associated with turbulent motion it is necessary to state clearly which effect we wish to measure quantitatively. For certain purposes the amount of motion is of interest, for it will determine the destructive forces which are brought to bear on any organism or material moving or suspended in the water, or it may determine the availability of certain foods and chemical substances necessary to life. Such effects are largely biological, but they are often included in forming a mental picture of the effects of mixing. In this determination we are concerned exclusively with the physical effect of turbulent motion in changing the mass distribution of the water so as to maintain residual currents to or from the mixing region. We shall attempt to measure not the energy of turbulent motion but the work done against gravity when mixing causes the density of the upper layers to be increased at the expense of the lower. Neither the mixing produced by convection currents, as in the winter overturn, nor the mixing from the external force of the wind, need concern us when comparing regions where the climatic conditions are appreciably the same.

Consider a mixing region in which fresh water is added locally so that there is a resultant inflow of heavy bottom water and an outflow of mixed water in the upper layers. It is assumed that the rate of addition of fresh water is known as well as the distribution of density throughout the mixing region. The following symbols will be used:

V_0 = cu. m./sec. of fresh water added at the surface within the region

V_b = cu. m./sec. of bottom water, density ρ_b or σ_b, drawn in from a depth z_b metres

z_m = depth in metres of outflow of mixed water of density ρ_m or σ_m at boundary of region

σ_1 or ρ_1 = mean density, surface to z_m

σ_2 or ρ_2 = mean density, z_m to z_b

Since the water moves horizontally as well as vertically during the mixing, σ_1 and σ_2 are not the mean densities at any one station but must be derived by studying the density distribution along the path of the currents. The fundamental expression for the work done in raising V cu. m. of water of density σ through h metres of mean density σ' is

$$\text{Work} = Vg(\sigma - \sigma')h \times 10^8 \text{ ergs} \qquad (1)$$

In the case of continuous mixing, the conservation of mass leads to

$$V_b = \frac{\sigma_m}{\sigma_b - \sigma_m} \times V_0 \qquad (2)$$

and the power, or rate of work, necessary to maintain the new density distribution is

$$\text{Power} = V_0 \left\{ \sigma_1 z_m + \frac{\sigma_m(\sigma_b - \sigma_2)}{(\sigma_b - \sigma_m)} (z_b - z_m) \right\} g \times 10^{-5} \text{ kilowatts} \qquad (3)$$

In the particular case of complete mixing from surface to depth z, where z is also the depth of inflow of heavy bottom water from outside the region

$$\text{Power} = V_0 \sigma_m z g \times 10^{-5} \text{ kilowatts} \qquad (4)$$

In the last two equations the result may be converted to horsepower by multiplying the number of kilowatts by 1.34.

We shall now apply these results to the bay of Fundy and to some of the individual mixing mechanisms which it contains. The results should be instructive as to the relative importance of such mechanisms.

BAY OF FUNDY, JUNE

Consider the mixing within the section from Petit Manan to Brier island, shown in figure 15. We shall choose such values for the various quantities in equation (3) as shall lead to a conservative estimate of the mixing in the bay.

$$V_0 = 1{,}500 \qquad \sigma_b = 26.5 \text{ at } z_b = 140$$
$$\sigma_m = 25.3 \text{ at } z_m = 10$$
$$\sigma_1 = 25.0, \quad \sigma_2 = 25.99$$

V_0 is obtained from the mean discharge into the bay of Fundy for June given in figure 3. All the other quantities except σ_1 are obtained by inspection of the density section in figure 15. For σ_1 the surface density at the points of fresh water inflow must be considered as well as σ_m. Fortunately, errors in σ_1 do not affect the final result greatly. σ_2 may be taken as the arithmetic mean between σ_m and σ_b, or the characteristic distribution of density between σ_m at z_m and σ_b at z_b may be plotted and the mean obtained graphically. This gives a value somewhat higher than the arithmetic mean because the density in the lower levels does not change as rapidly with depth as in the upper levels. Substituting the values given in equation (3) we get

Mixing Power, bay of Fundy, = 24,200 kilowatts = 32,450 H.P.

HEAD OF THE BAY, JUNE

Consider the region above the cape Spencer section (see figs. 1, 15, and 16). Here the water is all within the frictional influence of the bottom and stirring is so active that at every station the water is almost homogeneous from surface to bottom. Hence we can use equation (4) to calculate the mixing power. Figure 16 shows that the outflow of mixed water, which takes place on the New Brunswick side, lies between $\sigma_t = 25.0$ and 25.2. We shall take

$V_0 = 230$ (see fig. 3, regions 5, 6, 7), $\sigma_m = 25.1$, $z = 60$

and substituting in equation (4) we get

Mixing Power, head of bay = 3,400 kilowatts = 4,550 H.P.

QUODDY PASSAGES, JULY

Most of the fresh water discharged into the bays enters the Western passage, and the mixing in this passage finally achieves a homogeneous column, between $\sigma_t = 24.7$ and 24.8, which oscillates between stations K-C and S-H (see fig. 21). Some of this water is probably further mixed in Letite passage to about 24.5, so that if we take the mean density of the mixed water from the passages as $\sigma_m = 24.7$ we shall be close to the true value. For July, 1932, the mean fresh water discharge into Passamaquoddy bay was 2530 cu. ft./sec. or 71.6 cu. m./sec. To allow for the small discharge into Cobscook bay we shall take $V_0 = 80$ cu. m./sec. The average depth of complete mixing and the depth from which bottom water is drawn may be taken as 80 metres. Substituting in equation (4) the values

$V_0 = 80$, $\sigma_m = 24.7$ and $z = 80$, we get

Mixing Power, Quoddy passages = 1,550 kilowatts = 2,080 H.P.

SAINT JOHN RIVER ESTUARY, JUNE

Data given by Hachey (1935) may be used to calculate the density of the mixed water in Saint John harbour in June, 1930. Mean densities for the strongly stratified mixed water are 7.62 at the surface and 24.43 at 5 metres. From 5 metres the density increases very slowly to 24.57 at 15 metres. For June, 1930, the mean fresh water discharge at Saint John was 44,800 cu. ft./sec., or 1,270 cu. m./sec. Hence

$$V_0 = 1270 \qquad \sigma_b = 24.57 \text{ at } z_b = 15$$
$$\sigma_m = 16.03 \text{ at } z_m = 2.5$$
$$\sigma_1 = 11.82; \quad \sigma_2 = 23.64$$

and substituting in equation (3) we get

Mixing Power, Saint John estuary = 640 kilowatts = 858 H.P.

6. CONCLUSIONS

The foregoing calculations show that of the total mixing in the bay of Fundy which is effective in producing a circulation, 14% takes place at the head of the bay, 6% in the Quoddy passages, and 3% in the estuary of the Saint John river. These figures will vary with the season but they give a good quantitative basis for comparison of the various regions and lead to the following conclusions. The most important cause of the residual currents is the combination of the turbulent mixing *throughout the bay* with the large inflow of fresh water at Saint John. At the head of the bay, where the height of frictional influence of the bottom reaches the surface over a large area, we might expect the mixing to be large. On the contrary, the effective mixing is only 14% of that throughout the bay, because very little of the energy of turbulent motion is required to maintain the mixed condition by doing work against gravity. The effective mixing in the short and shallow Saint John estuary is very small, and the direct effect of the reversing falls on the currents of the bay is negligible. By this we mean that most of the work done in mixing the Saint John fresh water is supplied outside of Saint John harbour. The mixing produced by the Quoddy passages is important locally, but only amounts to about 6% of the total mixing in the bay of Fundy. It seems very unlikely that this amount of effective mixing, or any variation therein, can seriously affect the general circulation of the bay or of the neighbouring part of the gulf of Maine.

WINTER TEMPERATURES, 1931-32

In Passamaquoddy bay, midway between Navy island and Lewis cove, temperatures at 0, 10, and 25 metres:

Oct. 15, ——, 10.55, 10.39; Oct. 20, 11.0, 10.32, ——; Nov. 10, 9.6, 9.08, 9.12; Nov. 16, 8.17, 8.45, 8.88; Nov. 23, 8.8, 8.72, 8.81; Nov. 30, 7.8, 8.02, 8.38; Dec. 7, 6.4, 6.72, 7.22; Dec. 17, 4.7, 5.90, 6.13; Dec. 21, 4.7, 5.09, 5.38; Jan. 5, 3.2, 3.47, 3.53; Jan. 11, 3.0, 3.55, 4.00; Jan. 12, 3.3, 3.46, 3.90; Jan. 25, 2.7, 3.42, 3.84; Mar. 1*, 0.9, 0.81, 0.88.

In Outer Quoddy region, at station 5, temperatures at 0, 10, 25, 40, 75, metres:

Oct. 9, 11.1, 10.99, 10.93, 10.50, 9.47; Oct. 21, 10.21, 10.10, 10.07, 10.02, 9.78; Nov. 11, 9.5, 9.37, 9.36, 9.43, 9.51; Nov. 17, 9.06, 9.01, 9.09, 9.09, 9.09; Nov. 23, 9.5, 9.02, 9.17, 9.23, 9.29; Dec. 2, 8.2, 8.36, 8.49, 8.71, 9.19; Dec. 9, 7.6, 7.80, 7.56, 7.89, 8.40; Dec. 21, 6.4, 6.65, 6.70, 6.70, 6.65; Jan. 5, 5.3, 5.40, 5.49, 5.56, 5.52; Jan. 26, 4.1, 4.38, 4.52, 4.60, 4.74; Feb. 2, 3.2, 3.84, 4.18, 4.27, 4.39; Mar. 5*, 1.5, 1.40, 0.90, 1.62, 1.92.

North of Grand Manan island, lat. 44° 49.5′ N, long. 66° 42.5′ W, temperatures at 0, 10, 25, 40, 75 metres:

Nov. 12, 9.5, 9.48, 9.47, 9.46, 9.47; Dec. 11, 8.1, 8.05, 8.06, 8.09, 8.09; Jan. 29, 4.5, 4.59, 4.62 4.64, 4.94; Mar. 5*, 2.3, 2.20, 2.50, 2.20, 2 23.

Bay of Fundy, east of Grand Manan, lat. 44° 37.5′ N, long. 66° 23′ W, temperatures at 0, 10, 25, 40, 75 metres:

Nov. 12, 9.3, 9.24, 9.50, 9.54, 9.07; Dec. 11, 7.3, 7.23, 7.31, 7.99, 8.38; Jan. 29, 4.7, 4.82, 4.86, 5.04, 5.45; Mar. 5*, 2.0, 2.82, ——, 2.96, 2.70.

*Temperatures given for March are uncorrected readings.

TABLES OF TEMPERATURES, SALINITIES AND DENSITIES SPRING AND SUMMER, 1932

In the following tables the station data are given in the first column in this order: station number or name, date, time of first and last observations, wind and tide. The other four columns contain the depth in metres and the corresponding values of temperature, salinity and σ_t.

INDEX TO STATIONS

Regular stations are shown on maps in the following figures:

Bay of Fundy stations.......................................fig. 1
Off Grand Manan, P and WH sections.........................fig. 13
Grand Manan channel, Q and MC sections.....................fig. 14

Passamaquoddy bay A-D, and Cobscook bay 1-3......................fig. 23
Quoddy passages..fig. 21

Other stations in the Quoddy region used occasionally are located as follows:

SW stations lie between South Wolf and Bishop rock, Grand Manan, at the following distances from South Wolf: SW1, 2¼ miles (4.2 km.); SW2, 4¼ miles (7.9 km.); SW3, 5½ miles (10.2. km.)

EW stations lie between East Wolf and Deadman head, at the following distances from East Wolf: EW1, 1½ miles (2.4 km.); EW2, 2½ miles (4 km.); EW3, 3¾ miles (7 km.);

C stations, used on July 7 only, are on a line crossing Grand Manan channel from West Quoddy head, their positions being marked on figure 20.

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STATION	M	TEMP	SAL	σ_t
5, Apr 19	0	2.5	30.17	24.10
	10	2.59	30.72	24.53
16.19-50	25	2.36	31.20	24.93
strong S	40	2.38	30.55	24.41
L.W.16.25	75	2.36	30.97	24.74
5, Apr 19	0	2.64	30.55	24.40
	10	2.71	30.72	24.52
22.27-23.06	25	2.69	31.08	24.80
Light NW	40	2.57	31.24	24.95
H.W.22.40	75	2.54	31.91	25.48
5, Apr 20	0	3.0	-----	-----
	10	2.76	31.13	24.84
11.04-50	25	2.59	31.22	24.92
Light NW	40	2.58	31.27	24.97
H.W.11.05	75	2.51	31.85	25.44
5, Apr 20	0	2.81	31.31	24.99
	10	2.95	31.31	24.98
17.07-41	25	2.62	31.40	25.07
Light NW	40	2.56	31.51	25.16
L.W.17.15	75	2.51	31.35	25.03
19, Apr 22	0	2.5	31.65	25.28
	10	2.49	31.71	25.32
23.55-0.27	25	2.46	31.71	25.32
Calm	40	2.48	31.71	25.32
H.W.0.11	60	2.49	31.71	25.32
	100	2.51	31.71	25.32
19, Apr 22	0	2.48	31.18	24.90
	10	2.46	31.67	25.30
6.16-54	25	2.45	31.87	25.46
Light NW	40	2.39	31.92	25.51
L.W.6.34	60	2.36	32.00	25.57
	100	2.44	32.09	25.63
9, Apr 22	0	4.13	29.07	23.10
	10	3.59	29.58	23.54
12.31-13.21	25	3.25	30.37	24.20
Fresh NW	40	3.11	30.62	24.41
H.W.12.39	75	2.99	31.09	24.79
9, Apr 22	0	4.20	28.42	22.57
	10	3.98	29.31	23.29
18.44-19.19	25	3.05	30.35	24.21
Fresh NW	40	2.95	30.53	24.35
L.W.18.56	75	2.90	30.70	24.49
5, Apr 25	0	2.96	31.47	25.10
	10	2.79	31.51	25.15
9.27-10.07	25	2.69	31.60	25.22
Light NW	40	2.68	31.62	25.23
L.W.9.13	75	2.48	31.83	25.43
5, Apr 25	0	3.4	31.13	24.79
	10	2.80	31.49	25.13
14.54-15.17	25	2.79	31.51	25.15
Strong S	40	2.73	31.62	25.23
H.W.15.14	75	2.47	31.62	25.25
Centre Pass.	0	3.7	30.23	24.04
Bay, Apr 25	10	3.29	30.41	24.23
17.10-17.21	25	3.02	30.79	24.55
5, Apr 26	0	3.0	31.24	24.91
	10	2.93	31.36	25.02
10.17-39	25	2.96	31.40	25.05
Fog	40	2.71	31.62	25.23
L.W.10.10	75	2.76	31.49	25.13

STATION	M	TEMP	SAL	σ_t
5, Apr 26	0	2.9	31.53	25.15
	10	2.90	31.56	25.18
15.50-16.11	25	2.79	31.64	25.25
E, fog	40	2.69	31.64	25.25
H.W.16.15	75	2.79	31.64	25.25
T1, Apr 30	0	4.9	16.91	13.43
	5	2.78	23.44	18.73
11.42-54	10	1.51	31.00	24.83
Light E	25	1.36	31.15	24.95
L.W.14.15	35	1.35	31.80	25.48
T2, Apr 30	0	4.5	17.97	14.29
	5	2.83	25.12	20.06
12.17-46	10	1.86	30.12	24.11
Light E	25	1.43	31.80	25.47
	35	1.42	31.80	25.47
T3, Apr 30	0	4.7	17.79	14.14
	5	2.14	28.84	23.06
13.24-36	10	1.45	31.42	25.16
Light E	25	1.36	31.76	25.45
	40	1.44	31.85	25.51
T4, Apr 30	0	4.3	18.51	14.73
	5	1.64	31.06	24.86
14.12-50	10	1.50	31.27	25.05
Light E	35	1.48	31.83	25.50
	60	1.48	31.89	25.54
T5, Apr 30	0	5.2	17.34	13.75
	5	2.62	24.94	19.92
15.19-49	10	1.63	29.61	23.71
Light SxE	35	1.56	31.26	25.03
	60	1.56	31.94	25.57
T6, Apr 30	0	4.6	18.96	15.07
	5	2.11	28.77	23.00
16.19-36	10	1.45	29.99	24.03
Light SxE	25	1.47	31.87	25.53
	40	1.45	31.96	25.60
	75	1.49	31.96	25.60
T7, Apr 30	0	4.3	21.09	16.77
	5	2.05	28.51	22.82
17.17-37	10	1.49	31.44	25.18
Light S	25	1.34	31.80	25.48
	40	1.38	31.87	25.54
	75	1.89	32.07	25.66
L1, May 3	0	3.5	28.37	22.59
	5	3.03	28.62	22.83
3.42-55	10	1.89	31.09	24.88
NW cloudy	25	1.48	31.82	25.48
L.W.4.21	35	1.45	31.83	25.50
L2, May 3	0	4.3	26.42	20.97
	5	3.41	27.65	22.03
4.26-42	10	1.71	31.53	25.23
NW cloudy	25	1.48	31.78	25.45
	50	1.50	31.82	25.48
L3, May 3	0	4.7	24.07	19.09
	5	3.15	27.57	21.99
5.19-41	10	1.79	31.55	25.24
Fresh NW	25	1.58	31.94	25.57
	40	1.85	32.07	25.66
	75	1.98	32.14	25.71

STATION	M	TEMP	SAL	σ_t
L4, May 3	0	5.2	24.34	19.27
	5	2.70	28.75	22.95
6.06-26	10	1.89	31.94	25.55
Fog	25	1.94	32.18	25.74
	40	1.99	32.18	25.74
	75	2.04	32.21	25.76
L5, May 3	0	5.0	26.42	20.92
	5	2.61	31.13	24.85
7.00-30	10	2.35	31.65	25.29
Fog	25	2.05	32.10	25.67
	60	2.07	32.14	25.70
	100	2.07	32.18	25.73
L6, May 3	0	5.1	27.85	22.04
	5	3.48	31.53	25.10
7.58-8.19	10	3.52	31.64	25.18
Fresh NW	25	2.16	32.20	25.74
	60	2.08	32.20	25.75
	100	2.09	32.23	25.78
S1, May 4	0	3.2	29.43	23.46
	5	2.95	29.97	23.90
4.24-52	10	2.21	31.36	25.07
Light NW	25	1.64	31.82	25.47
L.W.5.03	40	1.78	31.98	25.59
	75	2.79	32.34	25.80
S2, May 4	0	3.5	28.82	22.95
	5	3.44	29.29	23.32
5.47-6.01	10	1.94	32.00	25.60
Light NW	25	2.64	32.29	25.77
	60	2.73	32.30	25.78
	100	2.99	32.36	25.80
S3, May 4	0	4.1	29.70	23.59
	5	3.86	30.64	24.36
6.39-7.07	10	3.50	31.62	25.16
Light NW	25	3.60	32.09	25.53
	40	3.79	32.34	25.71
	60	3.63	32.52	25.87
	100	3.24	32.59	25.97
S4, May 4	0	4.1	31.64	25.13
	5	3.95	31.64	25.14
7.55-8.16	10	3.81	31.67	25.19
Light NW	25	3.70	32.34	25.72
	60	3.62	32.52	25.88
	100	3.61	32.59	25.94
SW2, May 4	0	3.13	31.53	25.13
	5	2.97	31.53	25.14
16.15-53	10	2.89	31.58	25.19
Strong S	25	2.79	31.67	25.28
L.W.17.16	40	2.42	31.85	25.44
	60	2.48	31.85	25.44
	100	1.88	31.94	25.55
P1, May 18	0	4.0	31.69	25.18
	7½	4.10	31.71	25.18
16.42-55	20	4.12	31.74	25.21
S, hazy	35	3.69	31.74	25.25
P2, May 18	0	4.0	31.87	25.33
	7½	3.86	31.91	25.37
17.28-41	20	3.87	31.91	25.37
L.W.15.56	35	3.80	31.91	25.38

STATION	M	TEMP	SAL	σ_t
P3, May 18	0	3.9	31.94	25.39
	7½	3.77	31.94	25.40
18.14-49	20	3.79	32.01	25.45
	35	3.89	32.14	25.54
	60	4.07	32.29	25.64
WH3, May 18	0	6.7	30.66	24.06
	10	6.70	30.91	24.27
19.53-20.15	25	4.79	31.85	25.23
Light W	50	4.37	32.52	25.80
	100	4.37	32.74	25.97
WH2, May 18	0	6.3	30.50	23.99
	10	4.64	31.09	24.64
21.08-35	25	4.71	32.01	25.36
H.W.22.15	50	4.50	32.39	25.69
	100	4.16	32.66	25.93
WH1, May 18	0	5.8	30.26	23.86
	10	4.61	30.91	24.40
22.56-23.07	25	2.95	31.82	25.37
Light W	50	3.03	32.21	25.68
S1, May 19	0	5.9	30.34	23.91
	7½	3.62	31.33	24.92
8.25-50	20	3.64	31.51	25.07
Light N	40	3.47	31.67	25.22
L.W.4.28	75	3.43	32.36	25.76
S2, May 19	0	6.4	30.26	23.79
	5	5.40	30.59	24.16
9.22-10.05	10	4.31	31.20	24.76
	25	3.06	32.01	25.52
	50	2.96	32.18	25.66
	100	3.90	32.61	25.92
S3, May 19	0	7.1	30.25	23.69
	5	4.10	31.33	24.88
10.34-11.04	10	4.10	31.83	25.29
H.W.10.45	25	4.69	32.30	25.59
	50	4.32	32.48	25.78
	100	4.30	32.63	25.90
S4, May 19	0	8.5	29.92	23.25
	5	6.07	30.35	23.91
11.30-12.04	10	5.38	31.58	24.95
Calm	25	4.45	32.09	25.45
	50	4.32	32.39	25.71
	100	4.16	32.68	25.95
S1, May 19	0	7.2	30.05	23.52
	7½	4.48	30.88	24.49
13.15-29	20	3.61	31.40	24.99
	40	3.14	31.85	25.38
	75	3.30	32.14	25.60
19, May 19	0	4.6	31.53	24.99
	7½	4.26	31.53	25.02
14.44-58	20	3.71	31.82	25.30
L.W.16.50	40	3.69	31.85	25.34
	75	3.50	31.76	25.28
9, May 19	0	7.3	29.65	23.20
	5	7.08	29.72	23.29
17.48-18.00	10	6.81	29.90	23.45
Strong SW	25	5.06	31.00	24.53
	50	4.92	31.08	24.60

STATION	M	TEMP	SAL	σ_t
Letite Pass.	0	4.5	31.51	24.99
May 20	5	4.28	31.51	25.01
	10	4.32	31.53	25.02
12.06-18	25	4.61	31.67	25.11
H.W.11.34	35	4.03	31.67	25.17
Letite Pass.	0	5.9	30.82	24.29
May 30	5	5.38	30.82	24.35
	10	5.29	30.91	24.44
9.29-9.50	25	4.77	31.33	24.81
H.W.8.32	35	4.49	31.51	24.99
EW2, May 30	0	7.6	28.98	22.63
	5	6.38	30.14	23.69
11.03-15	10	5.93	30.55	24.08
	25	4.33	31.71	25.16
	40	3.65	31.80	25.30
5, May 30	0	6.8	30.44	23.88
	10	5.76	30.66	24.18
11.51-12.04	25	5.03	31.24	24.72
SE, clear	40	4.26	31.69	25.15
½ebb	75	3.65	32.14	25.57
SW2, May 30	0	7.6	28.98	22.63
	5	6.18	29.51	23.22
13.00-21	10	4.82	31.20	24.71
SE clear	25	4.54	31.35	24.85
	60	4.00	32.01	25.44
	100	4.03	32.39	25.74
19, May 30	0	7.2	30.03	23.50
	5	5.39	30.82	24.35
14.10-30	10	5.26	31.24	24.69
SW clear	25	4.64	31.53	24.99
L.W.14.25	50	4.08	31.85	25.30
	90	3.83	32.32	25.90
5, May 31	0	5.7	30.95	24.42
At H.W.	5	5.53	30.97	24.45
9.43-10.07	10	5.40	30.97	24.46
Strong SW	25	4.93	31.46	24.90
H.W.9.19	40	4.55	31.56	25.02
	75	3.85	32.18	25.77
5, May 31	0	5.7	31.15	24.57
At ½ebb	5	5.50	31.15	24.59
	10	5.47	31.15	24.59
12.27-51	25	4.58	31.51	24.98
Light SW	40	4.39	31.62	25.08
½ebb at 12.17	75	3.88	32.00	25.63
5, June 2	0	6.0	31.08	24.48
At ¼flood	5	5.17	31.31	24.76
7.40-8.05	10	5.16	31.35	24.79
Light NW	25	4.68	31.65	25.08
H.W.10.40	40	4.46	31.76	25.19
	75	4.79	32.05	25.38
SW2, June 2	0	6.1	31.08	24.47
	5	5.67	31.09	24.53
9.09-59	10	5.57	31.13	24.57
Light NW	25	5.11	31.44	24.87
Clear,calm	40	4.85	31.64	25.05
	60	4.30	32.07	25.45
	100	4.34	32.21	25.56

STATION	M	TEMP	SAL	σ_t
5, June 2	0	7.0	31.08	24.36
At H.W.	5	5.81	31.17	24.56
10.41-11.03	10	5.53	31.24	24.66
Calm	25	5.12	31.35	24.79
H.W.10.40	40	4.73	31.58	25.02
	75	4.20	31.98	25.39
5, June 2	0	5.8	31.29	24.67
At ½ebb	5	5.46	31.33	24.74
13.49-14.07	10	5.39	31.33	24.75
Fresh S	25	4.98	31.49	24.92
½ebb at 13.40	40	4.79	31.60	25.03
	75	4.24	32.16	25.53
Wilson's	0	5.6	31.31	24.71
Beach, June 2	5	5.68	31.31	24.70
15.10-25	10	5.65	31.31	24.71
Moderate S	25	5.61	31.33	24.72
	35	5.59	31.33	24.72
5, June 2	0	6.6	30.90	24.26
At L.W.	5	6.19	31.31	24.65
16.43-17.02	10	5.52	31.36	24.76
S, clear	25	5.17	31.55	24.92
L.W.16.40	40	5.14	31.58	24.97
	75	4.45	31.89	25.29
9, June 9	0	7.4	30.62	23.95
	5	7.10	30.82	24.14
9.35-10.00	15	6.48	31.09	24.43
After strong	30	6.46	31.13	24.47
S, L.W.9.13	50	6.34	31.20	24.54
Q1, June 13	0	6.5	31.82	25.00
	5	5.99	31.85	25.09
11.43-54	10	5.79	31.92	25.17
Cloudy	25	5.73	31.92	25.18
L.W.12.43	35	5.59	31.92	25.20
Q2, June 13	0	6.6	31.58	24.80
	5	6.21	31.62	24.88
12.16-38	10	6.03	31.65	24.93
SW,cloudy	25	5.47	31.83	25.14
	40	5.47	31.92	25.21
	75	4.77	32.29	25.57
Q3, June 13	0	6.3	31.80	25.01
	5	6.03	31.80	25.05
13.03-21	10	5.97	31.80	25.06
	25	5.47	31.80	25.11
	40	5.36	31.96	25.25
	75	4.93	32.16	25.46
Q4, June 13	0	6.0	31.87	25.11
	5	5.84	31.87	25.13
13.43-14.05	10	5.83	31.87	25.13
SW,cloudy	25	5.38	31.94	25.23
	40	5.43	31.98	25.25
	75	5.12	32.09	25.38
MC1, June 13	0	5.5	32.00	25.27
	5	5.39	32.00	25.28
11.44-58	10	5.38	32.00	25.28
SW, clear	25	5.37	32.05	25.32
L.W.12.43	50	5.34	32.05	25.32

STATION	M	TEMP	SAL	σ_t
MC2, June 13	0	5.7	32.00	25.24
	5	5.46	32.00	25.27
12.25-39	10	5.36	32.00	25.28
L.W.12.43	20	5.31	32.01	25.30
	40	5.31	32.01	25.30
	75	5.29	32.01	25.30
MC3, June 13	0	5.8	31.94	25.18
	5	5.45	31.94	25.22
13.08-24	10	5.37	31.98	25.26
	20	5.32	31.98	25.27
	40	5.31	31.98	25.27
	75	5.30	31.98	25.27
MC4, June 13	0	5.9	31.96	25.19
	5	5.43	31.96	25.25
13.57-14.11	10	5.33	31.96	25.26
	20	5.29	31.96	25.26
	40	5.30	31.96	25.26
	75	5.28	31.96	25.26
MC5, June 13	0	7.1	31.85	24.95
	5	6.02	31.85	25.09
14.39-15.09	10	5.59	31.85	25.14
	25	5.33	31.85	25.17
	50	5.30	31.85	25.17
Q4, June 13	0	6.4	31.87	25.06
	5	5.81	31.87	25.13
17.24-41	10	5.68	31.87	25.15
Light SW	25	5.43	31.87	25.18
Clear	40	5.44	31.89	25.19
	75	5.44	31.96	25.24
Q3, June 13	0	6.5	31.91	25.08
	5	5.59	31.91	25.19
18.03-24	10	5.43	31.91	25.20
	25	5.36	31.91	25.21
	40	5.36	31.91	25.21
	75	5.35	31.94	25.23
Q2, June 13	0	6.8	31.92	25.05
	5	5.47	31.92	25.21
18.45-19.06	10	5.48	31.92	25.21
Light SW	25	5.37	31.92	25.22
H.W.19.05	40	5.35	31.96	25.25
	75	5.31	31.98	25.27
Q1, June 13	0	5.8	31.94	25.18
	5	5.77	31.94	25.19
19.29-40	10	5.71	31.94	25.19
Hazy	25	5.71	31.94	25.19
	35	5.53	31.94	25.21
MC5, June 13	0	6.5	32.01	25.16
	5	6.30	32.01	25.18
17.23-34	10	6.23	32.01	25.19
Calm, clear	25	5.96	32.01	25.22
	50	5.89	32.01	25.23
MC4, June13	0	7.2	31.96	25.02
	5	5.88	31.98	25.20
18.00-21	10	5.74	31.98	25.22
H.W.19.05	20	5.70	32.00	25.24
	40	5.69	32.00	25.25
	75	5.67	32.03	25.28
MC3, June 13	0	8.2	31.89	24.83
	5	6.98	31.89	25.00
18.49-19.02	10	5.80	31.89	25.14
MC3	20	5.61	31.89	25.17
Calm	40	5.51	31.89	25.18
H.W.19.05	75	5.47	31.89	25.18
MC2, June 13	0	7.2	31.83	24.93
	5	5.65	31.83	25.12
19.30-43	10	5.39	31.83	25.15
	20	5.35	31.83	25.16
	40	5.32	31.83	25.16
	75	5.29	31.89	25.20
MC1, June 13	0	5.6	31.85	25.14
	5	5.45	31.85	25.15
20.06-16	10	5.39	31.85	25.16
Calm	25	5,38	31.85	25.16
	50	5.32	31.87	25.19
5, June 14	0	6.7	31.58	24.79
	10	6.70	31.58	24.79
13.26-39	25	6.24	31.62	24.88
SE, fog	40	6.06	31.71	24.97
L.W.13.40	75	4.93	32.03	25.36
Frenchman's	0	11.1	31.83	24.32
Bay, June 15	5	10.48	31.85	24.44
	15	7.13	31.89	24.98
15.04-15	30	6.40	31.92	25.10
Light W, clear	50	5.73	31.96	25.21
1, June 15	0	7.8	31.91	24.90
Petit Manan	5	7.10	31.91	25.00
	15	6.07	31.91	25.13
17.24-35	30	5.96	31.91	25.14
W, clear	50	5.96	31.92	25.15
2, June 15	0	7.0	32.16	25.21
	5	6.19	32.20	25.34
18.37-48	15	5.83	32.21	25.39
	35	5.77	32.21	25.40
	75	5.62	32.27	25.47
3, June 15	0	7.0	32.25	25.28
	5	6.77	32.27	25.32
20.01-13	15	6.06	32.29	25.42
	35	5.84	32.63	25.73
	75	5.83	32.72	25.79
4, June 15	0	9.0	32.54	25.21
	5	8.99	32.54	25.21
21.10-25	15	8.99	32.63	25.29
	35	7.34	32,66	25.55
	75	5.57	33.04	26.08
	150	6.49	34.09	26.79
5, June 15	0	8.0	32.50	25.33
	5	7.68	32.50	25.38
22.35-51	15	6.85	32.59	25.57
	35	5.51	32.79	25.89
	75	5.65	33.15	26.16
	150	6.09	33.75	26.58
6, June 15-16	0	7.3	32.10	25.12
	5	7.28	32.10	25.12
23.45-0.01	15	7.07	32.21	25.24
	35	6.58	32.47	25.50
	75	5.75	32.90	25.94
	150	6.28	33.87	26.65

STATION	M	TEMP	SAL	σ_t
7, June 16	0	8.2	32.45	25.26
	5	8.14	32.45	25.27
2.23-34	10	7.49	32.48	25.39
	25	6.91	32.57	25.54
	40	5.85	32.79	25.85
8, June 16	0	9.5	32.48	25.09
	5	9.49	32.48	25.09
3.28-43	15	8.46	32.48	25.25
	35	5.91	32.66	25.74
	75	5.34	32.95	26.04
	150	5.89	33.60	26.49
9, June 16	0	7.0	32.29	25.30
	5	6.85	32.43	25.44
4.43-58	15	6.91	32.54	25.51
	35	6.08	32.74	25.78
	75	5.98	32.79	25.84
	150	5.76	33.49	26.41
10, June 16	0	7.3	32.01	25.05
	5	7.22	32.03	25.08
5.51-6.07	15	7.12	32.07	25.12
	35	6.37	32.20	25.32
	75	5.76	32.84	25.90
	150	5.66	33.31	26.29
11, June 16	0	6.8	32.41	25.41
Brier I.	5	6.77	32.41	25.43
	10	6.68	32.45	25.47
8.08-19	25	6.62	32.48	25.51
	40	6.59	32.50	25.52
FH1, June 16	0	7.9	31.04	24.21
	5	7.78	31.04	24.23
20.06-17	10	7.76	31.04	24.23
Light NE	25	7.79	31.04	24.22
Water muddy	35	7.78	31.04	24.23
FH2, June 16	0	7.0	31.31	24.55
	5	7.02	31.31	24.54
21.24-37	10	7.03	31.31	24.54
Cloudy	25	7.04	31.31	24.54
	40	7.03	31.31	24.54
FH3, June 16	0	6.7	31.55	24.76
	10	6.60	31.55	24.77
22.46-23.01	25	6.59	31.55	24.77
	40	6.59	31.55	24.77
	60	6.58	31.55	24.77
FH4, June 17	0	6.5	31.69	24.90
	5	6.47	31.69	24.90
0.00-12	10	6.43	31.69	24.91
	25	6.49	31.73	24.93
	40	6.55	31.76	24.95
CS1, June 17	0	6.8	31.55	24.75
	5	6.69	31.55	24.76
5.57-6.09	10	6.67	31.58	24.79
Strong NE	25	6.62	31.62	24.83
	40	6.47	31.73	24.93
CS2, June 17	0	6.6	31.85	25.01
	5	6.47	31.85	25.03
4.36-49	10	6.46	31.85	25.03
Strong NE	25	6.45	31.87	25.05
Cloudy	60	6.33	32.00	25.17

STATION	M	TEMP	SAL	σ_t
CS3, June 17	0	6.9	32.27	25.31
	5	6.79	32.27	25.32
3.05-20	10	6.81	32.27	25.32
Cloudy	25	6.81	32.29	25.33
	60	6.80	32.34	25.37
CS4, June 17	0	7.0	32.01	25.09
	5	7.09	32.07	25.13
1.24-37	10	7.10	32.14	25.18
NE, cloudy	25	7.17	32.16	25.19
	50	7.23	32.25	25.24
12, June 17	0	7.0	32.30	25.31
(Prim Point)	5	7.18	32.34	25.32
12.58-13.08	15	6.98	32.38	25.38
Fresh ENE	30	6.90	32.39	25.40
H.W.10.30	50	6.88	32.39	25.41
13, June 17	0	7.5	32.36	25.29
	5	7.50	32.39	25.32
13.50-14.01	15	6.66	32.43	25.46
NE,overcast	35	6.46	32.43	25.49
	75	6.29	32.45	25.52
14, June 17	0	7.45	32.41	25.34
	5	7.40	32.43	25.37
14.50-15.01	15	7.36	32.43	25.37
Very rough	35	6.41	32.52	25.57
	75	5.93	32.63	25.71
15, June 17	0	8.4	32.12	24.98
	5	8.30	32.12	25.00
15.47-58	20	7.13	32.18	25.20
NExN,rough	43	5.52	32.32	25.52
	87	5.47	32.83	25.93
16, June 17	0	8.7	31.78	24.67
	5	8.46	31.78	24.70
16.57-17.18	15	6.56	32.12	25.23
	35	5.81	32.48	25.61
	75	5.23	32.79	25.93
	125	5.29	32.94	26.03
17, June 17	0	8.25	31.87	24.81
	5	8.24	31.87	24.81
18.13-36	15	7.62	31.91	24.93
	35	5.83	32.39	25.54
	75	5.36	32.92	26.01
	125	5.34	32.99	26.07
18, June 17	0	7.9	31.15	24.29
	5	7.82	31.15	24.29
19.32-44	15	5.86	31.83	25.10
Light NE	35	5.28	32.12	25.39
Calmer	75	4.81	32.63	25.85
19, June 17	0	5.85	31.92	25.17
	5	5.83	31.92	25.17
21.09-20	15	5.79	31.92	25.17
Light NW	35	5.75	31.92	25.18
	75	5.73	31.92	25.18
T1, June 18	0	9.7	27.79	21.42
	5	7.57	29.78	23.26
15.31-43	10	6.73	31.33	24.59
Hazy	25	6.57	31.60	24.82
	35	6.54	31.67	24.89

STATION	M	TEMP	SAL	σ_t
T2, June 18	0	10.3	27.47	21.06
	5	8.71	28.04	21.75
16.02-14	10	6.69	31.51	24.74
Hazy	25	6.59	31.74	24.93
	35	6.52	31.80	24.99
T3, June 18	0	8.6	30.19	23.45
	5	7.40	30.88	24.15
16.30-41	10	6.77	31.49	24.71
Hazy	25	6.57	31.73	24.92
	50	6.28	32.07	25.23
T4, June 18	0	8.3	30.70	23.88
	5	6.95	31.47	24.68
17.02-14	10	6.59	31.73	24.92
WSW,hazy	25	6.37	31.94	25.11
	60	6.17	32.10	25.27
T5, June 18	0	8.8	31.27	24.26
	5	6.49	31.91	25.08
17.34-53	10	6.42	31.92	25.10
	25	6.32	32.18	25.30
	40	6.09	32.18	25.33
	75	6.07	32.18	25.34
T6, June 18	0	9.6	31.64	24.42
	5	7.46	31.91	24.95
18.16-36	10	6.73	32.07	25.18
WSW,hazy	25	6.16	32.23	25.37
	40	5.84	32.27	25.44
	75	5.79	32.29	25.46
T7, June 18	0	10.3	31.58	24.25
	5	9.76	31.62	24.37
19.00-21	10	7.19	32.07	25.11
Strong S	25	5.96	32.29	25.44
	50	5.76	32.36	25.52
	90	5.75	32.36	25.52
5, June 24	0	7.0	31.85	24.96
	5	7.10	31.76	24.88
11.47-12.28	10	7.01	31.76	24.89
Partly cloudy	25	6.90	31.82	24.95
L.W.10.15	40	6.77	31.85	24.99
	75	5.64	32.27	25.47
Cobscook 1,	0	9.0	31.73	24.58
June 28	5	8.99	31.71	24.56
12.15-17	15	8.99	31.71	24.56
Cobscook 2	0	9.0	31.76	24.61
June 28	5	8.76	31.74	24.63
12.35-37	15	8.57	31.76	24.67
Cobscook 3	0	8.7	31.76	24.65
12.56-59	5	8.66	31.74	24.64
June 28	20	8.58	31.74	24.65
Pass. A	0	10.9	30.01	22.95
July 4	5	9.19	31.09	24.06
W, cloudy	10	8.58	31.44	24.42
12.12-23	20	8.31	31.60	24.59
	30	8.21	31.62	24.61
Pass. B	0	11.0	---	---
July 4	5	10.73	---	---
12.50-13.01	10	9.12	---	---
SW, cloudy	20	8.37	---	---
	30	8.05	31.65	24.66

STATION	M	TEMP	SAL	σ_t
Pass. C	0	11.0	30.82	23.55
July 4	5	8.89	31.36	24.32
13.30-40	10	8.57	31.49	24.46
Strong SW	25	8.00	31.65	24.67
Pass. D	0	9.9	31.15	23.98
July 4	5	9.44	31.24	24.13
14.08-21	10	8.33	31.53	24.52
Strong SW	25	8.27	31.64	24.62
Rain	40	8.15	31.65	24.65
C1, July 7 17.08	0	7.7	32.05	25.02
C2, July 7	0	7.7	32.14	25.09
	5	7.55	32.14	25.11
17.23-35	15	7.32	32.14	25.14
Moderate SW	35	6.98	32.14	25.19
H.W.14.05	75	6.80	32.23	25.29
C3, July 7 17.52	0	8.2	31.85	24.80
C4, July 7	0	9.1	31.49	24.38
	5	8.59	31.62	24.55
18.13-26	20	7.30	32.05	25.08
Light SW,fog	50	6.98	32.18	25.22
	100	6.56	32.38	25.43
C5, July 7	0	7.7	32.03	25.01
Bet. Bishop's Rock & SW3 July 7,19.00	0	11.3	31.65	24.14
SW3, July 7	0	9.7	31.13	24.00
	5	9.31	31.24	24.15
19.27-39	20	7.61	31.80	24.84
Light S	50	6.94	32.07	25.15
	100	6.32	32.43	25.51
Bet. SW3&SW1 July 7,19.58	0	8.7	31.56	24.50
SW1, July 7	0	8.8	31.49	24.43
	5	8.73	31.49	24.44
20.12-25	15	8.40	31.56	24.54
Light SxE,fog	35	7.66	31.74	24.79
L.W.20.25	85	8.06?	31.49?	24.53?
Bet. SW1 & South Wolf July 7,20.40	0	9.0	31.44	24.36
5, July 7	0	8.9	31.64	24.53
	5	8.87	31.64	24.53
21.07-21	15	7.69	31.78	24.81
	40	7.29	31.96	25.01
	75	6.21	32.38	25.47
EW1, July 7	0	8.2	31.65	24.64
	5	8.21	31.71	24.68
22.02-15	15	8.10	31.74	24.73
Calm, clear	25	8.06	31.76	24.75
	55	6.71	32.10	25.20
EW2, July 7 22.28	0	9.0	31.62	24.49

STATION	M	TEMP	SAL	σ_t
EW3, July 7	0	10.0	31.62	24.33
	5	9.80	31.60	24.36
22.41-54	15	8.45	31.73	24.66
Calm, clear	25	7.73	31.78	24.81
	40	7.25	31.94	25.00
Bet. EW3 & Deadman Hd. July 7,23.08	0	10.0	31.53	24.27
S1, July 7 16.41	0	11.8	30.30	23.01
S2, July 7	0	11.1	30.70	23.43
	5	10.83	30.66	23.45
17.10-26	20	7.44	32.29	25.24
Fresh SSW	50	6.34	32.81	25.80
Hazy	90	5.96	33.12	26.10
S3, July 7 17.50	0	10.8	30.99	23.71
S4, July 7	0	11.9	31.33	23.78
	5	11.83	31.31	23.78
18.21-37	15	11.73	31.40	23.87
Moderate SW	35	8.59	32.05	24.89
	75	6.61	32.83	25.79
	125	6.15	33.13	26.08
S5, July 7 19.02	0	11.5	31.56	24.04
S6, July 7	0	10.9	31.89	24.40
	5	11.18	31.87	24.34
19.32-44	20	10.03	31.96	24.60
Moderate SW	50	6.67	32.63	25.62
L.W.20.25	100	5.92	32.97	25.98
Midway S6 to L6,July 7 20.12	0	12.0	31.35	23.77
L6, July 7	0	11.5	30.77	23.42
	5	11.41	30.77	23.44
20.43-56	20	7.54	32.29	25.23
	50	6.37	32.65	25.67
	100	5.95	32.79	25.84
L5, July 7 21.22	0	11.0	30.84	23.57
L4, July 7	0	10.2	30.77	23.65
	5	9.54	31.35	24.19
21.44-56	15	7.51	32.29	25.23
Light WSW	35	6.27	32.45	25.53
	75	6.13	32.56	25.63
L3, July 7 22.10	0	10.8	29.58	22.62
L2, July 7	0	9.3	30.99	23.95
	5	8.57	31.35	24.34
22.27-38	15	8.34	31.56	24.55
	30	8.19	31.67	24.66
	50	7.82	31.82	24.82
L1, July 7 22.50	0	9.1	31.17	24.13

STATION	M	TEMP	SAL	σ_t
P·L, July 25	0	13.6	30.39	22.74
At L.W.	5	10.27	31.38	24.10
	10	10.07	31.64	24.34
11.16-29	25	9.71	31.73	24.47
Calm, clear	45	9.64	31.74	24.49
P·L. July 25	0	9.9	31.76	24.47
At ½Flood	5	9.80	31.74	24.46
	10	9.82	31.74	24.46
14.19-28	25	9.67	31.80	24.53
H.W.17.21	45	9.66	31.80	24.53
P·L, July 25	0	11.5	31.55	24.02
At H.W.	5	9.92	31.73	24.43
	10	9.73	31.78	24.50
17.18-28	25	9.72	31.80	24.52
Light NW	45	9.70	31.80	24.53
9, July 25	0	13.1	31.08	23.36
At L.W.	5	10.11	31.67	24.36
	15	9.80	31.82	24.52
11.30-44	30	9.65	31.99	24.62
L.W.11.11	50	9.56	31.99	24.64
9, July 25	0	11.6	31.51	24.08
At ½Flood	0	12.7	30.88	23.29
	5	10.85	31.51	24.11
14.06-23	15	10.53	31.55	24.19
Light N	30	10.14	31.71	24.38
Clear, hot	50	9.53	31.85	24.59
9, July 25	0	11.4	31.42	23.94
At H.W.	0	12.6	31.06	23.44
	5	10.82	31.58	24.17
17.16-34	15	10.43	31.60	24.25
	30	9.84	31.89	24.57
	50	9.56	31.92	24.65
P·L, July 26	0	12.2	31.35	23.73
At ½Ebb	5	10.07	31.65	24.35
	10	9.91	31.69	24.41
9.20-29	25	9.73	31.76	24.49
Clear	45	9.69	31.76	24.50
B·B, July 26	0	9.8	31.89	24.58
Ebb	5	9.67	---	---
10.15-28	10	9.57	31.83	24.58
SW, clear	30	9.34	31.91	24.67
	60	8.67	32.12	24.94
5, July 26	0	10.0	31.74	24.43
Near L.W.	5	10.10	31.74	24.41
	10	9.78	31.74	24.47
11.15-35	25	8.87	31.94	24.76
SW, clear	40	8.24	32.09	24.98
L.W.12.00	75	7.79	32.29	25.20
5, July 26	0	9.7	31.89	24.59
At ½Flood	5	9.35	31.92	24.68
	10	8.98	32.03	24.83
15.15-35	25	8.80	32.09	24.89
Strong S	40	8.08	32.18	25.07
	75	7.45	32.52	25.43
B·B, July 26	0	10.2	31.80	24.45
Flood	5	9.82	31.85	24.55
	10	9.58	31.85	24.59
16.10-23	30	9.31	31.89	24.66
Strong S	60	8.64	32.14	24.95

STATION	M	TEMP	SAL	σ_t
P.L, July 26	0	11.1	31.82	24.30
Flood	5	10.60	31.71	24.30
	10	10.23	31.71	24.36
16.58-17.09	25	9.70	31.83	24.56
Cloudy	45	9.69	31.89	24.59
9, July 26	0	13.7	30.48	22.79
At ½Ebb	5	11.01	31.44	24.03
	15	10.03	31.44	24.19
9.10-21	30	9.76	31.85	24.56
Light S	50	9.73	31.85	24.56
K·C, July 26	0	10.5	31.73	24.34
At Ebb	5	9.79	31.85	24.55
	20	9.72	31.85	24.56
9.48-51	40	9.65	31.89	24.60
B·W, July 26	0	10.55	31.85	24.42
At Ebb	5	10.30	31.85	24.47
10.22-25	10	10.26	31.85	24.47
SSW, hazy	20	9.96	31.89	24.55
S·H, July 26	0	9.6	31.96	24.67
At Ebb	5	9.33	31.98	24.72
	15	9.31	32.00	24.74
11.05-15	35	9.32	32.03	24.77
L.W.12.00	75	9.27	32.05	24.79
S·H, July 26	0	9.4	32.07	24.79
At Flood	5	9.23	32.07	24.82
15.33-46	15	9.02	32.12	24.89
Strong SSW	30	8.87	32.14	24.92
H.W.18.20	74	8.91	32.12	24.90
B·W, July 26	0	10.0	31.89	24.55
At Flood	5	9.77	31.91	24.60
16.27-30	10	9.63	31.91	24.62
Strong SSW	20	9.55	31.91	24.64
K·C, July 26	0	9.7	32.00	24.68
At Flood	5	9.42	32.00	24.73
16.59-17.01	20	9.42	32.00	24.73
SSW,overcast	40	9.39	32.00	24.73
9, July 26	0	11.8	31.47	23.92
At Flood	5	10.38	31.67	24.32
	15	9.95	31.78	24.47
17.26-37	30	10.00	31.80	24.48
Strong SW	50	9.86	31.85	24.54
Black Ledges	0	12.0	31.65	24.01
Aug 5	5	10.21	31.89	24.51
12.36-38	20	9.94	32.01	24.65
Fish I.	0	10.5	31.91	24.48
Aug 5, 13.01	5	10.10	31.94	24.57
Light S,clear	20	10.06	31.94	24.58
Lords Cove	0	11.4	31.83	24.27
Aug 5	5	10.38	31.89	24.48
13.23-25	15	10.22	31.91	24.53
Hospital-Bar	0	10.3	32.00	24.58
Aug 5	5	9.92	32.00	24.65
13.50-53	20	9.74	32.09	24.74
Casco-Deer	0	10.1	32.10	24.69
Aug 5	5	9.92	32.10	24.72
14.10-13	20	9.88	32.10	24.73

STATION	M	TEMP	SAL	σ_t
Indian River	0	10.1	32.05	24.65
Aug 5	5	10.00	32.05	24.67
14.36-38	20	9.95	32.05	24.68
K·C, Aug 5	0	10.3	31.98	24.56
	5	10.17	31.98	24.59
15.16-27	20	10.13	31.98	24.59
Calm. clear	40	10.01	31.98	24.61
Pass. A	0	13.7	31.17	23.31
Aug 5,16.13-16	5	11.08	31.53	24.08
Light S,clear	20	10.35	31.91	24.51
Pass. B,Aug 5	0	13.4	31.46	23.59
16.42-45	5	11.03	31.51	24.08
Moderate S	20	10.64	31.76	24.34
Pass. C,Aug 5	0	13.0	31.53	23.73
17.10-12	5	11.04	31.65	24.19
S, clear	20	10.48	31.80	24.40
Pass. D,Aug 5	0	14.3	31.06	23.10
17.43-45	5	12.20	31.33	23.72
S, clear	20	10.55	31.83	24.41
B·B, Aug 5	0	11.0	31.76	24.28
12.57-59	5	10.34	31.87	24.48
Light SSW	20	9.71	32.01	24.69
H.W.13.42	50	9.05	32.25	24.98
White Horse	0	10.75	31.94	24.46
Aug 5	5	10.13	31.94	24.56
13.23-25	20	9.55	32.10	24.78
	50	8.66	32.36	25.12
S·H, Aug 5	0	9.8	32.07	24.72
	5	9.20	32.21	24.93
13.49-14.00	15	9.17	32.23	24.95
Light SW	35?	9.83	32.10	24.74
Clear	75?	9.13	32.23	24.96
Windmill Pt.	0	9.75	32.10	24.75
Aug 5	5	9.87	32.10	24.73
14.26-29	20	9.88	32.14	24.76
Clear	50	9.44	32.14	24.83
Cobscook,	0	11.9	31.85	24.19
South Bay	5	11.12	31.89	24.36
Aug 6, 14.04	10	10.99	31.92	24.41
H.W.14.25				
Cobscook 1	0	11.0	31.94	24.42
Aug 6, 14.34	5	10.86	31.94	24.44
S, clear	15	10.70	31.94	24.47
Cobscook 2	0	11.0	31.96	24.44
Aug 6,15.00	5	10.66	31.96	24.49
S, clear	15	10.04	32.07	24.68
Cobscook 3	0	10.8	32.03	24.53
Aug 6,15.26	5	10.54	32.03	24.57
H.W.14.25	15	10.45	32.03	24.59
T1, Sept 3	0	12.9	30.88	23.25
	5	11.41	31.78	24.22
17.04-15	15	11.03	32.23	24.64
Calm, clear	25	10.99	32.27	24.68
	45	10.92	32.36	24.76

STATION	M	TEMP	SAL	σ_t
T2, Sept 3	0	14.7	28.87	21.35
	5	12.49	31.26	23.62
17.32-43	15	11.13	32.30	24.67
Calm, clear	25	11.05	32.38	24.74
	45	10.53	32.48	24.93
T3, Sept 3	0	12.9	30.90	23.26
	5	11.53	32.14	24.48
18.00-09	15	11.17	32.29	24.66
Calm, clear	30	10.73	32.41	24.83
	50	10.22	32.57	25.04
T4, Sept 3	0	12.4	31.60	23.90
	5	12.10	31.74	24.06
18.30-40	20	11.09	32.38	24.74
	40	10.09	32.57	25.06
	65	9.74	32.65	25.18
T5, Sept 3	0	12.0	32.23	24.47
	5	11.49	32.29	24.60
19.00-10	20	10.50	32.52	24.95
Calm, clear	40	9.78	32.66	25.18
L.W.19.39	65	9.61	32.70	25.24
T6, Sept 3	0	14.5	32.23	23.97
	5	13.12	32.27	24.29
19.33-42	20	10.23	32.63	25.09
	50	9.65	32.75	25.28
	75	9.49	32.75	25.30
T7, Sept 3	0	14.7	32.18	23.88
	5	13.49	32.21	24.16
20.00-15	20	10.21	32.59	25.06
	50	9.38	32.79	25.35
	100	8.93	32.79	25.42
Frenchman's	0	13.0	32.16	24.22
Bay, Sept 3	5	11.66	32.23	24.53
	15	10.92	32.29	24.70
17.23-44	30	10.61	32.32	24.78
Calm, clear	50	9.93	32.38	24.93
1,(Petit Manan)	0	11.1	32.61	24.92
Sept 3	5	10.46	32.61	25.03
	15	10.26	32.61	25.06
20.47-58	30	10.04	32.66	25.14
	50	9.81	32.70	25.21
2, Sept 3	0	10.0	32.63	25.13
	5	9.93	32.66	25.16
21.35-46	15	9.89	32.66	25.16
Calm, clear	35	9.90	32.66	25.16
	75	9.41	32.75	25.32
3, Sept 3	0	10.6	32.70	25.07
	5	10.03	32.75	25.22
22.27-38	15	9.11	32.84	25.44
	35	8.97	32.92	25.52
	75	8.90	32.95	25.56
4, Sept 3	0	11.75	32.52	24.73
	5	10.84	32.59	24.95
23.42-56	15	9.79	32.66	25.18
	35	9.05	32.84	25.45
	75	7.52	33.39	26.10
	150	6.57	34.14	26.83
5, Sept 4	0	12.0	32.63	24.77
	5	11.94	32.63	24.78
0.41-54	15	10.78	32.77	25.10
Clear	35	8.70	33.06	25.66
5, Sept 4	75	7.94	33.30	25.96
	150	6.65	34.13	26.80
6, Sept 4	0	13.0	32.66	24.60
	5	12.65	32.77	24.76
2.02-15	15	11.60	32.79	24.97
H.W.1.40	35	9.52	32.97	25.47
	75	7.30	33.48	26.20
	145	6.66	34.07	26.76
7, Sept 4	0	12.7	32.54	24.57
(G. Manan Bank)	5	11.60	32.70	24.90
3.16-26	15	9.39	32.99	25.50
	30	8.97	33.08	25.64
	50	7.81	33.31	26.00
8, Sept 4	0	13.4	32.74	24.58
	5	12.84	32.74	24.69
4.39-52	15	11.41	32.74	24.96
Calm	35	8.60	32.99	25.63
H.W.1.40	75	7.19	33.39	26.15
	150	6.59	33.96	26.68
9, Sept 4	0	12.2	32.63	24.73
	5	11.59	32.74	24.93
5.40-54	15	10.51	32.74	25.12
	35	8.13	33.12	25.80
	75	7.55	33.35	26.07
	150	6.75	33.87	26.59
10, Sept 4	0	10.5	32.81	25.18
	5	10.02	32.83	25.28
6.44-57	15	9.09	32.90	25.48
Light SE	35	8.40	33.08	25.73
	75	8.16	33.26	25.90
	150	7.01	33.62	26.36
11, Sept 4	0	9.5	32.83	25.36
(Off Brier I.)	5	9.42	32.83	25.38
8.11-22	15	9.23	32.90	25.45
Calm	30	9.09	32.92	25.50
	45	8.94	32.95	25.55
L1, Sept 4	0	12.6	30.95	23.37
	5	11.80	31.20	23.71
6.16-28	15	11.24	32.09	24.49
Calm, clear	30	10.90	32.25	24.67
L.W.8.01	50	10.08	32.48	25.00
L2, Sept 4	0	12.6	31.18	23.54
	5	11.92	31.74	24.10
6.49-58	15	11.38	32.20	24.55
	30	10.88	32.32	24.74
	50	10.49	32.47	24.92
L3, Sept 4	0	12.6	31.64	23.90
	5	12.31	32.16	24.35
7.18-30	20	10.47	32.43	24.89
Calm, clear	40	9.42	32.68	25.26
	75	8.96	32.77	25.40
L4, Sept 4	0	13.6	31.96	23.94
	5	12.94	32.25	24.30
7.54-8.05	20	9.44	32.63	25.22
Light NE	40	9.13	32.77	25.37
	90	8.74	32.79	25.45

STATION	M	TEMP	SAL	σt
L5, Sept 4	0	13.9	32.01	23.92
	5	13.28	32.14	24.14
8.31-43	20	9.19	32.74	25.33
Light NE	50	9.06	32.77	25.39
Clear	100	8.40	32.90	25.58
L6, Sept 4	0	14.9	32.00	23.70
	5	14.70	32.01	23.75
9.08-20	20	10.83	32.48	24.87
NE, clear	50	8.70	32.92	25.56
	100	8.44	32.94	25.61
12, Sept 6	0	10.6	32.66	25.04
(Off Prim Pt)	5	10.51	32.66	25.06
8.29-40	15	10.42	32.66	25.08
Fresh SSW	30	10.37	32.68	25.10
Overcast,fog	50	10.29	32.68	25.12
13, Sept 6	0	11.2	32.63	24.92
	5	11.12	32.63	24.93
9.24-34	15	10.04	32.70	25.17
SSW, fog	35	9.84	32.74	25.23
L.W.9.40	75	9.61	32.77	25.30
14, Sept 6	0	13.0	32.25	24.29
	5	12.96	32.25	24.30
10.25-35	15	11.96	32.32	24.54
Fresh SWxS	35	9.37	32.77	25.33
Fog	75	8.84	32.86	25.49
15, Sept 6	0	13.4	32.09	24.08
	5	13.32	32.10	24.11
11.29-46	15	10.60	32.25	24.72
	30	9.40	32.66	25.24
	52	8.83	32.81	25.45
	95	8.20	33.12	25.79
16, Sept 6	0	13.3	32.18	24.17
	5	13.29	32.18	24.17
12.38-50	15	11.94	32.27	24.50
Fresh SWxW	35	9.24	32.74	25.33
Fog	75	8.00	33.13	25.83
	125	7.78	33.17	25.89
17, Sept 6	0	13.6	32.14	24.08
	5	13.57	32.16	24.11
13.46-59	15	12.06	32.29	24.50
Fresh SW,fog	35	9.02	32.83	25.44
	70	7.93	33.06	25.78
	132	7.58	33.24	25.98
18, Sept 6	0	13.6	32.14	24.08
	5	13.49	32.18	24.13
14.57-15.07	15	12.87	32.25	24.31
H.W.15.39	35	9.47	32.74	25.29
	75	8.06	33.01	25.72
19, Sept 7	0	10.7	32.38	24.80
	5	10.68	32.38	24.81
7.31-41	15	10.44	32.43	24.90
Light SW	35	10.02	32.50	25.02
H.W.4.11	75	9.09	32.70	25.32
SC4, Sept 7	0	11.4	32.23	24.58
(Wolves Bank)	5	11.45	32.25	24.58
9.22-35	10	11.38	32.25	24.59
L.W.10.36	20	11.11	32.27	24.66
	40	10.71	32.38	24.80
SC3, Sept 7	0	11.4	32.27	24.60
	5	11.07	32.29	24.67
SC3, Sept 7	15	11.01	32.29	24.68
10.03-15	35	10.80	32.38	24.79
Calm, cloudy	70	8.64	32.86	25.52
	120	8.37	32.95	25.64
SC2, Sept 7	0	11.8	32.23	24.50
	5	11.27	32.27	24.63
10.44-56	15	10.89	32.36	24.76
Calm	30	10.36	32.43	24.91
	60	9.61	32.63	25.19
	110	8.46	32.94	25.60
SC1, Sept 7	0	11.6	32.27	24.57
	5	11.27	32.29	24.64
11.30-42	15	10.85	32.38	24.78
Light NW	35	10.30	32.47	24.95
Mostly cloudy	75	9.32	32.70	25.29
CS1, Sept 8	0	12.9	32.07	24.17
	5	12.50	32.07	24.24
11.00-12	15	12.28	32.12	24.33
Calm, cloudy	30	11.96	32.21	24.46
	50	11.69	32.30	24.57
CS2, Sept 8	0	12.2	32.30	24.47
	5	11.87	32.30	24.54
12.23-34	15	11.31	32.48	24.78
Calm, cloudy	30	11.07	32.52	24.86
	60	11.05	32.52	24.86
CS3, Sept 8	0	11.0	32.65	24.97
	5	10.79	32.65	25.00
13.45-55	15	10.69	32.65	25.02
	30	10.66	32.68	25.05
	60	10.60	32.68	25.06
CS4, Sept 8	0	11.0	32.66	24.98
	5	11.00	32.66	24.98
ExS, cloudy	15	10.93	32.66	24.99
15.08-18	30	10.94	32.66	24.99
	40	10.94	32.66	24.99
FH4, Sept 8	0	11.3	32.65	24.91
	5	11.29	32.65	24.91
16.21-31	15	11.29	32.65	24.91
Cloudy	30	11.26	32.65	24.92
	50	11.25	32.65	24.92
FH3, Sept 8	0	11.8	32.50	24.70
	5	11.87	32.50	24.69
17.14-24	15	11.88	32.50	24.69
Moderate ExS	30	11.88	32.50	24.69
Cloudy	60	11.90	32.50	24.69
FH2, Sept 8	0	12.5	32.27	24.40
	5	12.55	32.27	24.39
18.06-15	20	12.56	32.29	24.40
E, cloudy	40	12.51	32.29	24.41
FH1, Sept 8	0	13.3	31.98	24.01
	5	13.31	31.98	24.01
19.11-22	15	13.30	31.98	24.01
Fresh ExN	40	12.68	32.16	24.28
5, Sept 12	1	12.77	32.07	24.00
	7	11.36	32.30	24.63
17.06-29	20	11.18	32.30	24.66
Light N,clear	40	10.78	32.45	24.85
L.W.16.00	75	9.71	32.70	25.22

STATION	M	TEMP	SAL	σ_t
M1, Sept 29	0	11.3	32.50	24.80
(Machias-Seal)	5	11.17	32.52	24.84
	10	11.14	32.52	24.84
16.32-52	20	11.09	32.52	24.85
W, clear	40	10.99	32.52	24.87
Heavy swell	75	10.98	32.54	24.88
M2, Sept 29	0	11.4	32.47	24.76
	5	11.16	32.50	24.82
15.45-16.05	10	11.00	32.54	24.88
W, clear	20	10.86	32.54	24.90
L.W.16.52	40	10.78	---	---
	75	10.77	32.56	24.94
M3, Sept 29	0	11.1	32.56	24.88
	5	11.09	32.56	24.88
15.03-16	10	10.87	32.56	24.92
W, clear	15	11.01	32.56	24.90
	40	---	32.61	---
M4, Sept 29	0	10.8	32.57	24.94
	5	10.69	32.57	24.96
14.27-39	10	10.69	32.57	24.96
W, clear	25	10.65	32.57	24.97
	50	10.70	32.57	24.96
MC1, Sept 29	0	11.2	32.47	24.80
	5	11.00	32.47	24.83
14.39-50	10	11.00	32.48	24.84
W, clear	25	11.00	32.48	24.84
Heavy swell	50	11.00	32.48	24.84

STATION	M	TEMP	SAL	σ_t
MC2, Sept 29	0	11.0	32.50	24.85
	5	10.96	32.50	24.86
15.16-38	10	10.94	32.50	24.86
	20	10.97	32.50	24.85
	35	10.96	32.52	24.88
	70	10.98	32.52	24.87
MC3, Sept 29	0	11.0	32.50	24.85
	10	10.94	32.54	24.89
16.23-40	20	10.93	32.54	24.89
	35	10.93	32.54	24.89
	70	10.94	32.54	24.89
MC4, Sept 29	0	10.9	32.56	24.91
	10	10.93	32.56	24.91
17.03-12	20	10.91	32.56	24.91
Light NE	40	10.93	32.56	24.91
Clear	75	10.91	32.56	24.91
MC5, Sept 29	0	10.9	32.56	24.91
	5	10.92	32.56	24.91
17.37-46	10	10.90	32.56	24.91
	25	10.92	32.56	24.91
	50	10.89	32.59	24.94

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THE WASTING DISEASE OF ZOSTERA MARINA[1]

I. A Phytological Investigation of the Diseased Plant

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At the time that this study was begun, mid-summer, 1933, an epidemic, wasting disease had almost entirely destroyed the normally dense beds of the common marine eel-grass, *Zostera marina*, along the Atlantic coasts of North America and Europe. Since the plant is a prominent member of the shallow water community, sheltering a variety of larval and small sea animals, serving substantially as food for migratory game birds, and checking erosion of the bottom, and because the leaves are used for packing, upholstering, insulating, and other commercial purposes for which they are often peculiarly desirable, the disappearance of the eel-grass became a problem of practical concern. It was recognized, too, that the extensive and persistent wasting of *Zostera* might indicate phytopathological relationships in the sea as significant as the more evident conditions in land vegetation. A further impetus was given this investigation by the popularization of a number of physical and chemical hypotheses for the depletion, of restricted application, and usually of a prejudicial nature.

In France, Holland, Denmark, and Canada investigations were already in progress (6), (7), (11), (13), (18). The history of the disease here and abroad, the current condition of the eel-grass beds, and the economic and ecological implications of the wasting have been developed by a number of observers, and comprehensive summaries have been published from time to time by the U. S. Bureau of Biological Survey and others (1), (3), (6), (7), (10), (14).

This paper is an account of investigations upon the pathology of the diseased eel-grass and upon the specific parasitic nature of an unidentified *Labyrinthula*, an amœba-like organism with mycetozoan affinities, found in the leaves of the plant over the entire range of the epidemic condition. They were begun in the attempt to extend the findings of Messrs. Fischer-Piette, Heim, and Lami of France, who early reported a pathogenic bacterium as active in the diseased *Zostera* beds of their coast, and the work of Dr. H. Petersen of Copenhagen and Miss I. Mounce of Ottawa, who had studied a fungus associated with the wasting in Danish and Canadian waters, respectively (6), (11), (12). To these ends our results were negative (16). None of the bacteria isolated from diseased plants demonstrated pathogenic behavior in inoculation tests, and we failed to find any satisfactory physical association with the symptoms in leaves, stems, or roots in a variety of live specimens taken from the neighborhood of Woods Hole, Massachusetts, or in preserved material sent from many points along the American coast. From further exchange of specimens we were able to establish that though the fungus, *Ophiobolus halimus*, a new species described by Mounce and Diehl, was undoubtedly very abundant along the Canadian, Danish, and English coasts, it appeared only infrequently in diseased eel-grass taken from representative beds running from the coast of Maine southward, and that its development in these sporadic cases was incomplete (12), (17).

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Nevertheless, the symptoms of the wasting disease were identical in the exchange specimens and preparations taken from many parts of the American and European coasts, and these have remained constant through the epidemic's duration.

Investigation of the Diseased Plant

The foliage of infected beds is represented by short, young, rapidly growing, green leaves, eight to twelve centimeters in length, which may not show the splotching and dark streaking characteristic of the disease; by leaves of medium development, badly discolored and spotted with brown or black; and by the wilted basal fragments of older leaves sloughed away shortly after the disintegration of the greater part of their green tissues. Usually, the spotting is confined to the leaf epidermis, but it may arise in any green tissue, develop into plaques of considerable area, or form mosaics of widely scattered, darkened cells. The streaking, due to the serial infection of the larger, longitudinally disposed mesophyll cells, is more striking; it is generally sharply bounded by the longitudinal mesophyll spaces and terminated by the lateral septa (Fig. 1). Its margins spread rapidly, from three to five centimeters a day, or at higher rates during the warm summer when the disease is most active.

Often, but not always, the cuticle and cortex of the stem are irregularly pigmented with dark brown and black; the condition is not uniformly associated with the disease. After defoliation of the plant, through local activity of the parasite in the leaves, the stem may persist for one or two seasons to produce several new shoots each season —manifest in the apparent redevelopment of wasted beds. Eventually the reserve food supply, the accumulation of which has been limited by wasting, is exhausted and the weakened stems are invaded by bacteria, fungi, and attending saprophytes; the less vascular true roots decompose rapidly in the mud.

Microscopic examination of discolored and streaked tissue does not always reveal the protozoan parasite with which this paper is concerned; the reason for this discrepancy will be clear when its life history is described. On the other hand, the changes that can be directly observed following experimental infection of the leaf are identical with those given by histological preparations of the diseased plant from naturally infected beds. Within a few hours after the cells have been entered by the parasite, the chloroplasts become olive or straw colored and either pass to the periphery of the cell where they adhere in masses, or coalesce near the center. Soon afterward they fragment, and the small particles of chloroplast material become dispersed through the cell or coagulate into dark, irregular clots. The nucleus persists for a long time after the breakdown of the chloroplasts, but finally takes on a spherical outline, granular texture, and brown or black pigmentation; often it is hidden by debris. In addition, dark globules of resinous substances, apparently produced by the injured cell itself, and not identified with any of the broken structures, make their appearances at intervals along the cell wall.

No changes attributable to the direct attack of the parasite upon the stems and roots could be observed; though the organism was found in the cells of the stem cortex several times, it was never abundant there nor uniformly associated with the discoloration of those parts. The damage brought about by the protozoan parasite is reflected systemically only through the destruction of the plant's food-synthesizing mechanism. Death follows the loss of the photo-synthetic function of the green leaves and the exhaustion of reserve food in the stems.

DEMONSTRATION OF THE *Labyrinthula* IN DISEASED EEL-GRASS

The spindle-shaped cells and interconnecting system of pseudopodia peculiar to the *Labyrinthulæ* and characteristic of the protozoan parasite of eel-grass were first observed in stained sections of diseased leaves taken from the region of Nantucket, Massachusetts, in the spring of 1934. That they had been overlooked until this time may have been due to their unusual distribution in the infected leaf, always well in advance of the visible streaking and discoloration itself, in the green tissues beyond the borders of the visible symptoms, and also to their very slight refractility. Their staining, too, is highly specific and difficult; to date a sequence of safranin, carbol-thionin, and Orange G. dyes, though uncertain in results, has given the best demonstration in formol-acetic-alcohol preserved field specimens. In these stained preparations the spindle-shaped cells of the *Labyrinthula* occurred with such persistence and were so suggestively oriented in the pathological picture that they were singled out as being in some way related to the disease.

A careful re-examination of specimens received from many points south of Woods Hole to Beaufort, N. C., confirmed the association in those waters, and later, when specimens were exchanged with Miss Mounce in St. Andrews, N. B., and with Mr. Tutin in Plymouth, England, the relations in these regions became evident also. Not long afterward, viable *Labyrinthulæ* were demonstrated by these investigators in their respective localities. Working independently, Mr. Loraine Young observed and studied the organism in diseased leaves in returning beds near Mt. Desert Island, Maine.

Dr. Frederick S. Sparrow of Dartmouth College identified the organism as one of the *Labyrinthulæ*, a family of the *Proteomyxa*, characterized by peculiar interconnecting pseudopodia; he also made many valuable suggestions relating to the culture and manipulation of the form.

In many features the *Labyrinthula* in *Zostera* is similar to the members of the family that have been described as parasitic upon marine algæ (2), (4), (9). It is not possible to identify the species with any of these at this time, however.

As found in the infected plant, the *Labyrinthula* may appear as a number of individual, colorless, slightly refractile, spindle-shaped cells from 10 to 20 mμ long and 5 to 8 mμ in diameter, distributed at random or in unrelated clusters through the green tissues and longitudinal spaces of the mesophyll (Fig. 2); as net-like aggregates of individuals connected together by a web of fine, branching, terminally secreted pseudopodia similarly disposed in the parasitized leaf (Fig. 3); as pseudoplasmodia formed of many individual spindles closely massed into thick cords or less regular strands (Fig. 4); or as what is apparently a resting stage—cyst-like, spherical bodies, about 6 to 10 mμ in diameter, light brown in color, surrounded by less dense, thick cuticles, and occurring mixed with residues in the older infected tissues (Fig. 5).

The spindles are motile; in the net-like organization they glide along the interconnecting pseudopodial web at rates in excess of 50 mμ per minute. They tend to concentrate in newly invaded tissue entrance to which is gained by local digestion of the cell walls. The pseudoplasmodium, sometimes relatively massive, also performs progressive movements, though not so rapidly as the individual cells; terminal masses of spindles may disperse to form a number of more lively branches (F

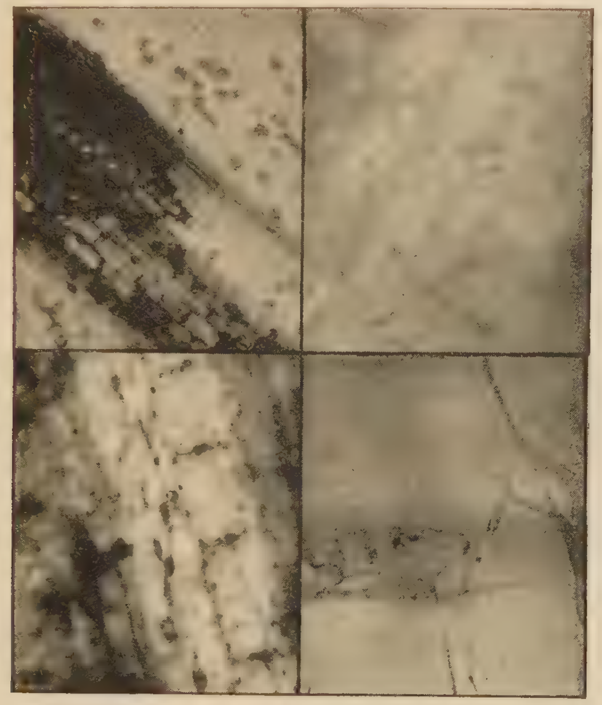


FIG. 1 FIG. 2

FIG. 3 FIG. 4

PLATE I

FIG. 1. Typical symptoms of the wasting disease in the leaf. Note extensive streaking in the mesophyll and mosaic infection of epidermal cells at upper right. Photomicrograph of clove oil-cleared preparation, stained with safranin—× 410.

FIG. 2. Individual spindle cells of *Labyrinthula*. No evidences here of pseudopodial net-structure. Photomicrograph from living preparation—× 480.

FIG. 3. Chain-like aggregates of connected spindles extending through longitudinal mesophyll space at boundary of infected zone. Note broken tissue at left and healthy mesophyll cells at right. Photomicrograph of living preparation—× 445.

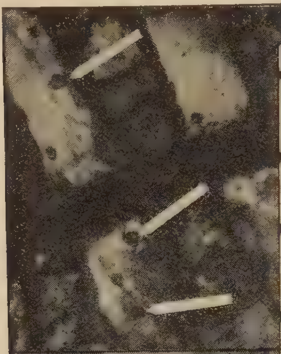
FIG. 4. Pseudoplasmodium in recently infected mesophyll tissue. Note early stages of degeneration in invaded mesophyll cells at left. Photomicrograph of living preparation—× 480.

All of these behaviors may be observed readily in damp cell mounts of excised, living, infected leaf tissue, and they may be extended to the study of the parasitic behavior by adding fresh, uninfected tissue to these mounts, a procedure giving an excellent demonstration of the migration of spindles and pseudoplasmodia into new host tissue.

Demonstration of Parasitism

A method of this design was employed in establishing the parasitic nature of the *Labyrinthula* found in eel-grass. Thirty-six damp cell, hanging drop preparations were made, each consisting of small tangential sections of living, uninfected leaf held against the under side of the cover-glass by a thin droplet of Seitz-filtered sea water in which, at

Fig. 5



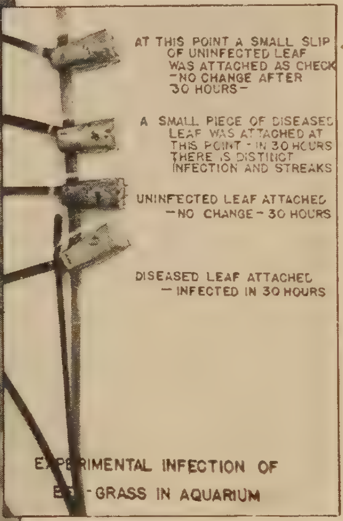

AT THIS POINT A SMALL SLIP OF UNINFECTED LEAF WAS ATTACHED AS CHECK —NO CHANGE AFTER 30 HOURS—
A SMALL PIECE OF DISEASED LEAF WAS ATTACHED AT THIS POINT - IN 30 HOURS THERE IS DISTINCT INFECTION AND STREAKS
UNINFECTED LEAF ATTACHED —NO CHANGE - 30 HOURS
DISEASED LEAF ATTACHED — INFECTED IN 30 HOURS
EXPERIMENTAL INFECTION OF
E -GRASS IN AQUARIUM

Fig. 7

Fig. 6

Plate II

Fig. 5. Cyst-like resting stages of the *Labyrinthula* lying in mesophyll spaces of blackened leaf—× 475.

Fig. 6. Dissolution of pseudoplasmodium into individual spindles. Here the centrally placed "vacuoles" may be distinguished. Photomicrograph of living preparation—× 1520.

Fig. 7. Demonstration of inoculation method. This leaf was taken from an aquarium experiment. In the field the inocula and checks were spaced at intervals of about four inches. Here the tendency of inocula to overrun checks is already evident.

a distance of about a millimeter from the test tissue, small pieces of diseased leaf containing viable *Labyrinthula* cells were also placed. Care was taken to avoid serious contamination.

Within eight to forty-eight hours the migration of motile spindles or the extension of pseudoplasmodia from diseased sections to the originally uninfested tissue and the invasion of the new host was evident in these preparations.

In these recently invaded pieces of host tissue the progress of disintegration was identical to that observed in sections of the living, diseased leaf studied earlier. Thirty of these preparations gave positive results, while ten check mounts containing green tissue and no "inocula" demonstrated that the tissue might be maintained in good health under the conditions of the experiment. One of these checks became contaminated by an air fungus, but nowhere else in these tests did mycelium appear.

Field Inoculation Experiments

That damp cell inoculation of excised leaf tissue may not indicate the parasitic habit of the *Labyrinthula* in nature is quite clear, but this criticism is effectively answered in field experiments repeated a number of times in selected eel-grass beds in Hadley's Harbor, near Woods Hole, during the summers 1934 and 1935.

Here healthy plants were inoculated by fastening to their leaves small pieces of diseased leaf, and check preparations were made by attaching pieces of normal leaf, or bits of paper to the same leaves. These were usually arranged alternately as shown in Fig. 7. Small cork clamps held the inocula and checks in place and great care was exercised to avoid mechanical injury of the test plant. The experiments during late summer, 1934, were directed toward determining the validity of this technique and adapting it to the more detailed studies that followed, but it was notable in these preliminary trials, repeated four times in two separate beds, and using from twenty to twenty-five tests in each trial, that the plants uniformly showed a degree of infection greater than 50 per cent at the end of two days exposure. The inoculated leaves were always marked with the symptoms of the disease generating from the points at which the inocula were attached, and the checks were free from any discoloration. Sections prepared from the newly infected leaves invariably showed heavy invasions of viable *Labyrinthulæ*, and of no other form, and such sections attached to clean plants brought about infection in the new host.

During the following summer, 1935, the field inoculation experiments were resumed in more detail to confirm the impressions of the previous year and to discover why the *Ophiobolus* did not appear in the inoculated leaves, though the mycelium had been found occasionally in specimens taken from nearby beds. The same method of inoculation was followed; about sixty inoculations and checks were prepared each time, but instead of removing all of the plants at the end of two days as before, part were removed and examined after one day, another aliquot after two days, and the remainder after three days.

These specimens were studied very closely; free-hand sections were prepared from both checks and inoculations and inspected under the high dry powers of the microscope. Table I summarizes the results of this search.

TABLE I

Incidence of Labyrinthula and other Invaders in Field Inoculation Experiments on Zostera marina

	Specimens taken after		
	24 hrs.	2 days	3 days
Number of inoculations	14	13	25
Number of inoculations showing symptoms of disease	8	9	22
Number of inoculations showing invasion by *Labyrinthula*	7	9	22
Number of inoculations showing invasion by bacteria or fungi	0	0	3‡
Number of checks	14	9	22
Number of checks showing streaks or other symptoms	0	3*	12†
Number of checks showing invasion by *Labyrinthula*	0	2*	11†
Number of checks showing invasion by bacteria or fungi	0	0	0

* Two of these checks were obviously overrun by extensive streaking arising from the inoculated region of the same leaf. The third showed some slight disintegration but no invaders—perhaps mechanical injury.

† In ten cases there was evident overrunning of the checks by extension of streaking from the point of inoculation. One is a case of spontaneous infection, clearly, because the inoculation in that case did not "take."

‡ The form appeared to be a filamentous fungus, but the mycelium was very poorly developed and mixed in with *Labyrinthula* and debris.

Later in the summer the experiments were repeated with some modifications that were designed to cut down the tendency of inoculations to overrun the check areas. These changes were not successful, but the results obtained confirm those secured earlier in the season and are given in Table II.

TABLE II

Incidence of Labyrinthula and other Invaders in Field Inoculation Experiments on Zostera marina

	Specimens taken after		
	24 hrs.	2 days	3 days
Number of inoculations	14	13	24
Number of inoculations showing symptoms of disease when removed	9	9	21
Number of inoculations showing invasion by *Labyrinthula*	10§	11§	22
Number of inoculations showing invasion by bacteria or fungi	0	0	3‡
Number of checks	14	10	22
Number of checks showing streaks or other symptoms	0	3*	12†
Number of checks showing invasion by *Labyrinthula*	0	3*	12†
Number of checks showing invasion by bacteria or fungi	0	0	0

* Despite wider separation of checks and inoculations the three checks were in these cases completely overrun by the development of streaking from the point of inoculation.

† In nine cases there was obvious overrunning of the checks. In two cases the check had become infected and had inoculated the leaf to which it was attached; in the other, the leaf had become infected and had inoculated the check.

‡ Fine mycelium in two cases; in the other distinctly heavy development of thick-walled mycelium.

§ Indicating infection so recent that the recognizable symptoms of darkening have not yet developed.

CULTURE OF THE *Labyrinthula*

A number of unsuccessful attempts have been made to transfer the *Labyrinthula* from its host to artificial media of various types. We have also tried species of *Bryopsis* and *Cladophora* as substitute hosts, choices determined by previously reported parasitism of these algæ by *Labyrinthulæ* (4).

Large numbers of spindles and masses of pseudoplasmodia free of obscuring host tissue could be obtained for morphological study, however, by culturing small pieces of infected leaf in sealed, hanging drop mounts. When these were exposed to diffused daylight for a few hours at room temperatures, the spindles migrated to the periphery of the supporting droplet in cord-like aggregates, sprays, and clusters.

If desired, the cover-slip could be lifted from the slide and the host tissue removed with fine tweezers to leave an unobstructed field in which the movement and development of the *Labyrinthula* might be studied over a period of four to eight hours.

Some cursory inoculation experiments using the isolated *Labyrinthulæ* as inocula have not given satisfactory results.

Discussion and Summary

From distribution studies on specimens representing the range of the wasting disease and taken over a period of three years, it appears that the *Labyrinthula* demonstrated in these experiments is universally associated with the epidemic condition. It did not occur, for example in eel-grass from Nanaimo, B. C., where the wasting disease has not been active, though the leaves of the plants were marked by lesions of various bacteria, fungi, and worms.

Histological examination and inoculation experiments indicate the true parasitic nature of the *Labyrinthula*. The rapidity with which it produces infection in these experiments is commensural with the aggressive habit of the disease in nature, and in this respect it seems to be the only organism transferred in a time interval comparable with the severity of the disease. The appearance of mycelium after several days, following the invasion by *Labyrinthulæ*, suggests a minor rôle for the fungus. Until this is definitely established by inoculation tests in the more northern waters the alternative of two active parasites must be considered. This does not seem likely, however, for the *Labyrinthula* is present and viable in the middle Atlantic regions throughout the year—it is notably more destructive in the late summer. If the *Ophiobolus* be a true parasite, its parasitic habit must be restricted to the Canadian and north European waters where it reaches its complete development.

From its observed behavior the *Labyrinthula* appears to be a specific parasite of *Zostera marina* L., but until the life history of the organism has been studied more carefully, it seems unwise to constitute a new species. It will be necessary, too, to attempt further host transfer experiments and to search for the *Labyrinthula* among related plants and members of the same community.

No attempt has been made in this paper to consider pertinent epidemiological problems; these are reserved for a report on field studies now in progress.

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FURTHER EXPERIMENTS ON THE FEEDING OF CALANUS FINMARCHICUS[1]

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INTRODUCTION

The prominent position of copepods in the food cycle of the sea has caused various investigators to study conditions influencing their production—in particular their food supply. Since previous observations on the food relationships of copepods were meager and conflicting, a series of experiments was initiated at the laboratory of the Woods Hole Oceanographic Institution in an effort to throw light upon this problem (Clarke and Gellis, 1935).

In their previous work these investigators obtained most satisfactory results with *Calanus finmarchicus*. It was found that individuals provided with sea water which had been passed through filter paper lived and moulted in large numbers, whereas other individuals, provided with sea water from which all particulate matter had been removed by means of a membrane filter, failed to moult and eventually died. Since the copepods throve in water from which the larger constituents of the phytoplankton—chiefly diatoms—had been removed, it was evident that this species at least could live on the small pelagic organisms, or nannoplankton, and perhaps actually did so in nature.

The further experiments on *Calanus* about to be described were undertaken in order to test the whole question more thoroughly, and, it was hoped, to ascertain at the same time which of the many components of the nannoplankton are chiefly concerned. There exist in the sea many bacteria, unicellular algæ, and protozoans which are small enough to pass through the pores of the rather coarse filter paper used (Whatman No. 12). Since bacteria were expected to be numerically most abundant, we began our scrutiny of the nannoplankton by testing this group as a possible source of food for *Calanus*.

EXTENSION OF EXPERIMENT USING CONTINUOUSLY FLOWING MEDIA

In the first of the present experiments, it was proposed to control more carefully than previously the bacterial population present in the flasks by using measured amounts of known strains of bacteria and by keeping careful track of subsequent changes in the population. Using the same method as Clarke and Gellis, continuously flowing media were supplied to flasks in which copepods were confined. One flask received water filtered through a Berkefeld cylinder of porosity W (which was found to remove all bacteria and to be more convenient than the membrane filter used previously). A second flask received Berkefeld-filtered water which had been inoculated with a small amount of a mixed suspension of three types of common marine bacteria. A third flask was supplied with a large amount of the same bacteria in Berkefeld-filtered water. At the end of four days bacterial counts showed that the first flask did not remain sterile and the desired quantitative difference between the second and third flasks was not maintained. Since the bacterial population in the flasks was not satisfactorily controlled, a different procedure was obviously necessary, but the experiment was useful in demonstrating the extreme rapidity with which the bacterial situation can alter in culture flasks.

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[1] Contribution No. 92, Woods Hole Oceanographic Institution.

Attempts to Free Copepods of Bacteria

The difficulties cited above would have been avoided, had it been possible to remove all bacteria from the copepods before commencing the experiment. Attempts to wash the animals free of bacteria by passing through the flask in which they were confined about sixty liters of water in eight hours resulted in a reduction of the bacterial count from over 10,000 to under 10 per cc., provided the animals were transferred to a fresh sterile flask twice during the washing period. Encouraged by this great reduction, we constructed a special washing tube consisting of a test tube (12.5 × 2.8 cm.) to the bottom of which was sealed an elbow of small bore glass tubing (Fig. 1). A glass bead allowed water to enter from below, but prevented the escape of any copepods when the flow of water ceased. Sea water collected at about three hundred yards from shore was passed through filter paper and then through the Berkefeld filter. The continuous flow, which was maintained from the filter, was divided into two parts each of which ran through a cooling coil and then was introduced at the bottom of one of the special washing tubes suspended in a water bath at 12° C. The upper end of the washing tube was closed with a two-hole rubber stopper through which passed (1) an outflow tube, the mouth of which was covered with bolting cloth, and (2) a second tube containing a cotton plug, which was kept closed until the end of a run, when it was used to equalize the pressure in the washing tube with that of the atmosphere. The outflows of the two washing tubes joined and were connected by way of two carboys to an aspirator which drew water through the whole system. A negative pressure of from 440 to 340 mm. of mercury as measured by a manometer in the system was maintained during the washing. Tests showed that this reduced pressure had no harmful effect upon the copepods.

Filter, cooling coils, washing tubes, and outflow tubes were sterilized in an autoclave. Twenty *Calanus* were introduced into each tube and washed for two or three hours with twenty liters of sea water. At the end of the washing periods the animals were poured into flasks of sterile water cooled to 12° C. This water had been passed through a Berkefeld filter, and then heated in the flask for thirty minutes at 90° C. Bacterial counts made on these flasks shortly after adding the copepods amounted to from 0 to 12 bacteria per cc. After standing overnight

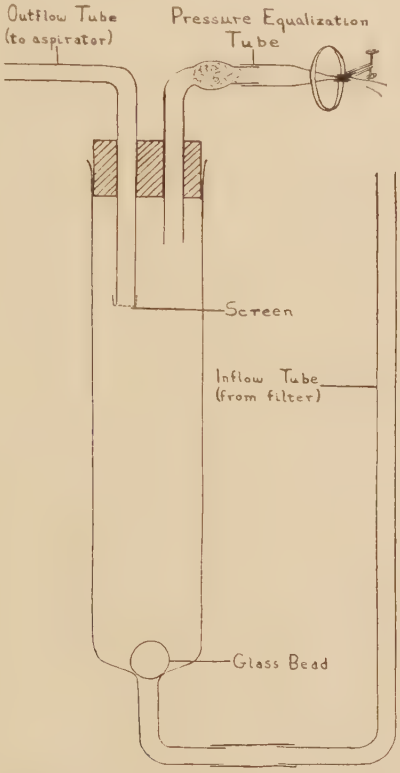

FIG. 1. Washing tube for removing bacteria from *Calanus*.

the counts rose to from 60 to 400 per cc. This concentration of bacteria we believe to be negligible in so far as the nutritional needs of copepods are concerned (see below).

THE AVAILABILITY OF BACTERIA IN HIGH CONCENTRATIONS AS FOOD FOR CALANUS

Four lots of twenty animals each were washed daily by the method described above. Two of these groups, No. 1*a* and 1*b*, were each poured after washing into a 250-cc. flask containing 150 cc. of sterile water prepared as described above. Lot No. 2 was placed in paper-filtered sea water. Lot No. 3 was placed in water treated as for groups 1*a* and 1*b*, but subsequently inoculated with a loopful of bacteria[2] scraped from an agar slant. A bacterial count was made on each flask after the copepods had occupied it for approximately twenty hours. The animals were then transferred to the washing tube by means of a sterile wide-mouthed pipette. The copepods in all four groups were subjected to equal manipulation which did not appear *per se* to cause injury. A considerable number of animals were lost, however, by being caught on the sides of the tube during pouring. In reporting the results of the experiment these animals are not considered (Table I).

The numbers of bacteria in these flasks varied considerably, but were consistently very much smaller in flasks No. 1*a* and No. 1*b* than in flasks No. 2 and No. 3. During the first nine days both flasks No. 1*a* and No. 1*b* gave counts close to 500 per cc. Subsequently the counts rose markedly to average between 2,000 and 4,000 bacteria per cc., and on one day (forty hours after washing) were about 10,000 per cc. in each flask. In flask No. 2 the counts ranged from 50,000 to 800,000 per cc. and averaged 250,000. Bacterial counts in flask No. 3 fluctuated from 300,000 to 1,500,000 per cc. with an average of 600,000. From the nutritional point of view, flasks No. 1*a* and 1*b* may be considered sterile because, as will be shown below (Table III), the relatively small number of bacteria present would provide a negligible amount of nutriment. The concentration of bacteria in flask No. 3 was many times greater than has ever been found in the sea. In flask No. 2 small flagellates were present also, but time did not permit a quantitative estimation to be made.

The apparent paradox of the highest death rate occurring in the flasks best supplied with food may possibly be explained by the fact that in flask No. 2 six of the deaths (50 per cent) and in flask No. 3 two of the deaths (20 per cent) occurred during moulting, whereas in flasks No. 1*a* and 1*b* there were no indications of moulting. The copepods in flasks No. 2 and 3 were apparently receiving enough food to carry them to the moulting stage, but not enough to enable them to pass this critical period. It is possible that in flask No. 3 *Calanus* did not utilize the bacteria in suspension, but rather fed on the small amount of solid matter unavoidably added with the inoculum. The starved animals lived longer on the average than those with a little food, because they did not grow, and did not attain any critical stage. Since in the experiments of Clarke and Gellis *Calanus* moulted successfully when supplied with paper-filtered water, the attendant conditions must have been more favorable in some respect. Possibly more food was made available by the use of continuously flowing water.

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[2] These bacteria were contributed by Dr. Selman A. Waksman. They belonged to a common marine species listed as No. 18 in his collection.

TABLE I

Bacteria in high concentrations as food for Calanus. Percentage of animals living after number of days indicated at left. Twenty animals at start.

	Flask No.	1*a*	1*b*	2	3
	Treatment of sea water	Sterilized		Paper filtered	Bacteria added
	Accidental deaths	7	6	7	8
days					
0		100	100	100	100
3		80	100	100	88
6		64	100	87	75
9		57	93	69	67
12		54	93	38	50
15		54	64	8	33
18		31	43	8	17

Two conclusions may be drawn from this experiment:

(1) *Calanus* will live without growing for over two weeks under starvation conditions.

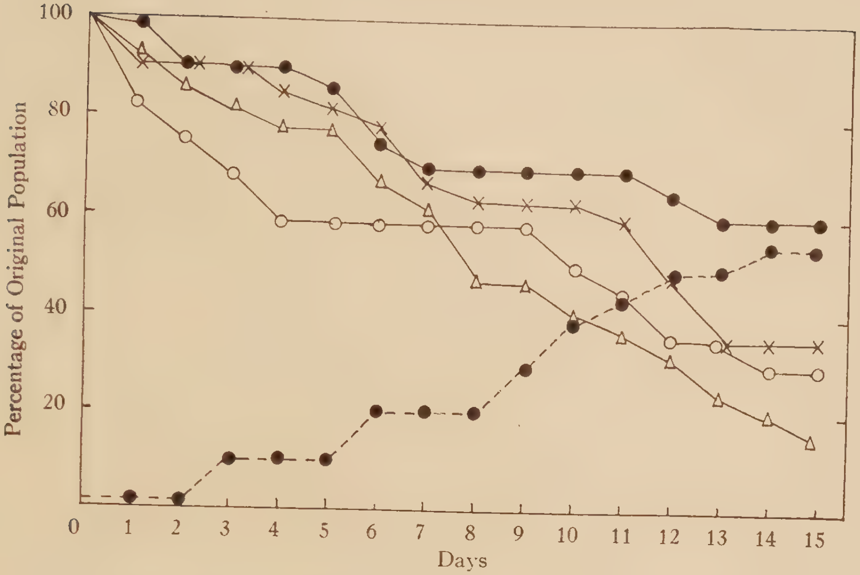
(2) Bacteria, even in high concentration, are not an adequate food for *Calanus.*

SEPARATION OF MICROÖRGANISMS INTO VARIOUS SIZES

Since bacteria were found to be unimportant as a source of food for *Calanus,* an attempt was next made to determine the size range of the organisms actually used as food by this copepod among the various other types of nannoplankton. For this purpose the animals were placed in harbor water which had been passed through a graded series of filters as indicated in Table II.

Duplicate groups "*a*" and "*b*" were first set up in each series with twenty animals each. Some unknown factor, probably a contamination of the harbor water, caused a large number of deaths on the second and third days of the experiment. Consequently the copepods from each pair were united in one container, and a new group "*c*" started in each series. The toxic agent, however, probably influenced subsequent results, for the death rates in combined "*a*" and "*b*" (hereafter called "*ab*") are in every case higher than those in the corresponding "*c*" groups. Excluding the first three days, group "*ab*" ran for fifteen days and group "*c*" for eleven days. The animals, which were kept in covered glass dishes set in a water bath at 15° C., were transferred daily to clean containers of freshly prepared sea water. Samples of water were centrifuged from time to time, and microscopical examinations of the organisms thrown down were made.

In going from untreated water to water passed through finer and finer filters one finds (Table II and Fig. 2) a consistent decrease in the ability of *Calanus* not only to moult successfully but also to survive. This is especially true if adults are disregarded, since they survived equally well under all conditions of these experiments—probably because they have stopped growing and are no longer dependent upon a regular food supply. It might be concluded from these results that *Calanus* lives best on the larger planktonic forms—diatoms, peridinians etc.—which were found abundantly in the harbor water, and which were held back by the paper filters. Another interpretation is possible, however. Microscopic examination of centrifuged samples of the paper-filtered water revealed numbers of minute flagellated organisms, but there were even more of these in similarly centrifuged samples of unfiltered water. Evidently many of the smaller organisms were caught in the meshes of the filter of each grade along with the larger ones with the result that a purely qualitative separation according to size was not attained. Therefore, it is impossible to judge from these results whether the differences between the welfare of the copepods in the several experiments were due to quantitative differences in the supply of flagellates and other small organisms, or to qualitative differences in the types of organisms available. Since bacteria were abundant in all containers (Table II), it is again clear that they are not an adequate food for *Calanus*.



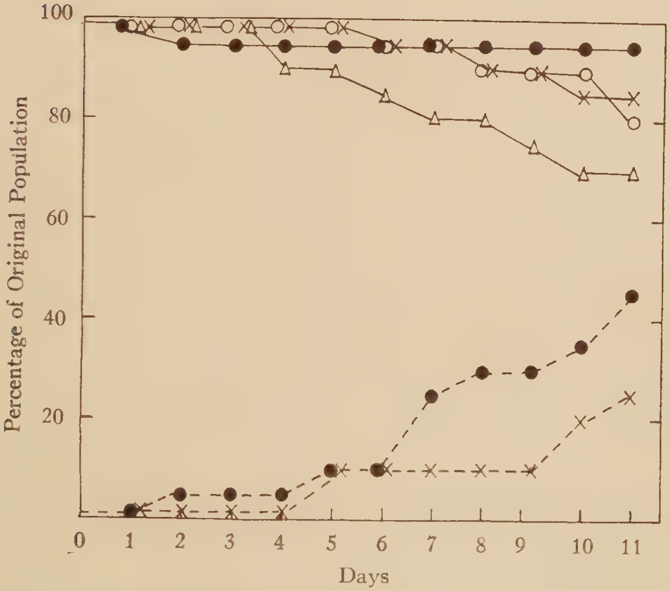


FIG. 2*a*. Series *ab*. Survival and moults of *Calanus finmarchicus* in water passed through different types of filters. Percentage of original population surviving shown by solid lines; percentage of original population moulting shown by broken lines.

Solid circles, unfiltered; crosses, Whatman 12; open circles, Whatman 40; triangles, Berkefeld W.

FIG. 2*b*. Same for series *c*.

TABLE II

Test as food for Calanus of microörganisms separated into various sizes.
Roman numerals refer to copepodid stages.

Series No.	Filter used	Population at start	Number of moults	Died during moult	Died, not during moult	Population at end	Bacteria per cc. on third day
1 *ab*	Untreated	5 IV	1	2	2	0	50,000
		12 V	10	0	2	1	
		3 VI	0	0	2	11*	
1 *c*		4 IV	4	0	0	0	
		14 V	5	0	1	12	
		1 VI	0	0	0	6	
2 *ab*	Whatman No. 12	2 IV	0	1	1	0	250,000
		15 V	0	6	5	4	
		5 VI	0	0	1	4	
2 *c*		5 IV	4	0	1	0	
		12 V	1	0	2	13	
		2 VI	0	0	0	3	
3 *ab*	Whatman No. 40	4 IV	0	1	0	0	560,000
		15 V	0	0	10	5	
3 *c*		4 IV	1**	1	1	1	
		12 V	0	1	1	11	
		4 VI	0	0	0	4	
4 *ab*	Berkefeld W	5 IV	0	1	4	0	400,000
		21 V	0	0	18	3	
		2 VI	0	0	0	2	
4 *c*		16 V	0	0	6	10	
		4 VI	0	0	0	4	

* Includes two males. All other Stage VI recorded are females.

** This moult occurred on first day, and was probably started when animal was captured.

THE NUTRITIONAL REQUIREMENTS AND THE FILTERING RATE OF CALANUS

Our search for the organisms which actually do serve as food for *Calanus* would be considerably narrowed if we could show that certain types are so sparsely represented in the sea that a copepod could not take in a sufficient number of them during the day to meet its nutritional requirements. The daily food requirements of a stage V *Calanus* during the summer have been calculated by Marshall, Nicholls, and Orr

(1935) on the basis of the oxygen consumption of a large number of individuals, as 0.013 mg. of carbohydrate or 0.005 mg. of fat. To obtain an approximate idea of the volume of water which a stage V *Calanus* would be required to filter to obtain this amount of nutriment, we have estimated the food content of the different elements of the phytoplankton and nannoplankton per unit volume of sea water at a station occupied on July 5, 1935, and located 7 miles south of the entrance to Vineyard Sound—a locality where *Calanus* occurred abundantly throughout the summer.

TABLE III

Daily filtering requirement. Volume of water containing sufficient organisms of certain types to supply the daily nutritive needs of a stage V *Calanus finmarchicus.*

Organisms	Number of cells	Calculated weight	Nutritive equivalent carbohydrate	Daily filtering requirement
	per cc.	*mg./cc.*	*mg./cc.*	*cc.*
Diatoms and peridinians V.S.	100	1.25×10^{-3}	1.4×10^{-4}	93
"Flagellates" V.S.	800	2.3×10^{-4}	4×10^{-5}	325
Bacteria V.S.	20,000	7.8×10^{-6}	1.3×10^{-6}	10,000
Bacteria	1,000	3.9×10^{-7}	6.5×10^{-8}	210,000
Bacteria	1,500,000	5.9×10^{-4}	9.8×10^{-5}	140

Notes: Composition of organisms assumed as follows:

	Percentage			
	Water and inert	Protein	Fat	Carbohydrate
Diatoms and peridinians.	90	4	1	5
"Flagellates"	84	12	0.5	3.5
Bacteria.	84	12	0.5	3.5

V.S.—Data based on quantitative analysis of water samples taken at the Vineyard Sound whistle buoy July 5, 1935.

If all three types of organisms served as food, the daily filtering requirement will be 72 cc.

The mass per cc. of diatoms, peridinians, and "flagellates" has been estimated from cell measurements on preserved material made by Miss Lois Lillick. The density of the living cells has been taken as equal to that of sea water. The mass of bacteria per cc. has been calculated from plate counts made by Dr. Margaret Hotchkiss. Each organism has been considered as a cylinder 0.5μ in diameter and 2μ long with the density of sea water. The analyses of Brandt (1898) were used as a basis for the assumed composition of diatoms and peridinians; those of Buchanan and Fulmer (1928) were used for the bacteria. We have found no published analyses of flagellate composition, and have considered it as similar to that of bacteria. Since these analyses were based upon mixed plankton samples, the values assumed and the results obtained (Table III) must be regarded as rough approximations only. The volume of water has been calculated which would have to be filtered if the copepod lived exclusively on one type of organism in the concentration in which it existed at the station considered.

Up to the present time no measurements have been made to our knowledge of the volume of water *Calanus* can effectively filter per day.[3] As measured from the drawings of Cannon (1928), the filtering surface of the appendages has an area of 0.12 sq. mm. To filter in 24 hours the minimum of 72 cc. of water (Table III) an average rate of flow through the filter of 6.9 mm. per second would be required. Whether this is a reasonable value in view of the fact that the appendages were observed by Cannon to make 10 strokes per second is a matter for speculation.

A direct measurement of the filtering rate was attempted in some entirely preliminary experiments in which *Calanus* was allowed to " feed " for a certain number of hours in a suspension of carmine particles, the concentration of which was determined before and after the feeding period. The suspension was made up in sea water and filtered through absorbent cotton. The concentration of the fine particles remaining in suspension was measured with a hemacytometer. From 10 to 15 cc. of this suspension were placed in a small glass dish and cooled to 12° C. in a water bath. Five specimens of *Calanus* were introduced on a small lifter of bolting cloth. The amount of water added with the animals caused no appreciable dilution of the carmine suspension. At intervals the concentration of carmine particles remaining in suspension was determined, and an examination made for fecal pellets containing carmine. Such pellets remain intact and do not confuse the results. A control maintained to check the effects of settling showed that carmine is unsatisfactory for use over long periods, since it settles slowly, and gradually goes into solution. For short periods, however, these effects can be neglected without seriously affecting the results. We are searching for a more satisfactory suspension with which to continue work.

The equation used to calculate the amount of water filtered over a given period of time was derived as follows. Let: C = concentration of particles in the suspension; V = volume of water per copepod; N

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[3] Harvey, Cooper, Lebour, and Russell (1935) report that " The copepod *Eurytemora hirundoides* has been observed by Lucas (private communication) to eat as many as 5,000 cells of the very small diatom *Nitzschia closterium* hourly, or 120,000 per day."

= number of particles per copepod; W = volume of water filtered per copepod. Then:

$$dN = -dWC,$$

$$dC = \frac{dN}{V},$$

$$-dWC = V\ dC,$$

$$W = V\ ln \frac{C_1}{C_2}\cdot$$

C_1 and C_2 indicate respectively the concentrations of particles at the beginning and end of a period of observation. The amount of water filtered in twenty-four hours has been calculated for one series of experiments (Table IV). The discrepancy between the value calculated after approximately six hours, and that calculated on the basis of longer periods is probably due to the fact that errors in counting have a greater effect on the results when the reduction of particle concentration is small.

TABLE IV

Filtering rate of Calanus. In each experiment 5 stage V *Calanus* were placed in 20 cc. of carmine suspension.

Experiment No.	Relative concentration carmine		Duration	Water filtered	Water filtered per day
	Start	Finish			
			hours	*cc.*	*cc.*
3	97	63	5.75	1.72	7.16
4	97	60	5.50	1.93	8.4
5	97	45	17.5	3.23	4.22
6	97	45	18.0	3.23	4.31
7	97	28	24.25	4.96	4.91
8	97	30	24.0	4.68	4.68
				Average	5.61

DISCUSSION

The results from these experiments on the filtering rate would appear to indicate that a *Calanus* cannot filter during the course of a day a sufficient volume of water to satisfy its nutritional needs if food organisms are actually as sparse as is apparently the case at the station considered. But little reliance should be placed as yet upon these entirely preliminary tests, although it is hoped that this method of investigating the filtering ability of copepods will prove valuable when perfected. The figures do show, however, that the bacteria would have to be many times more concentrated than they have ever been found in the sea in order for enough of them to exist in a volume of water which a copepod could reasonably be expected to filter in a day. This conclusion together with the results of the feeding experiments described above seems definitely to rule the bacteria out as a source of food for *Calanus*.

If copepods feed on diatoms the filtering of a smaller amount of water would be necessary, according to our results, than would be the case if " flagellates " were used provided that the number of flagellates in sea water has been correctly estimated. The total volume of the small, delicate, and easily destroyed species in the nannoplankton may turn out to be greater than supposed when adequate methods for their quantitative enumeration have been developed.

There is no doubt that the ratio of diatoms to copepods in the water is sufficiently great to meet the nutritional needs of *Calanus* if they are suitable for food and sufficiently concentrated. At the station considered only one *Calanus* was caught for each 28 liters of water theoretically strained by the net. Even though other organisms compete for the same food the potential supply would seem adequate since the rapid reproduction of the phytoplankton during periods of activity is well known.

The fact that food organisms are not evenly distributed either spatially or chronologically must also be considered. *Calanus* appears to be adapted for prolonged periods without food, since individuals in our experiments lived for nearly three weeks under starvation conditions. We have calculated the theoretical time of survival of *Calanus* assuming that metabolism continues at a normal rate under conditions of starvation, and that the total fat content is available as a reserve source of food. The average weight of fat per stage V *Calanus* in August in Loch Fyne is 0.094 mg. (Orr, 1934). Since the daily nutritional requirement of each animal is 0.005 mg. of fat (Marshall, Nicholls, and Orr, 1935), the fat reserve would last nineteen days. In early May the fat content per individual averages 0.026 mg., while the nutritional requirement is 0.003 mg. This represents a nine-day reserve. These calculations compare favorably with the results of our experiments when individual differences between animals are considered.

Before summarizing we wish to point out the gaps in our knowledge of the nutrition of *Calanus*, gaps which must be filled before a complete quantitative discussion can be given. We do not yet know the exact types of organisms utilized by *Calanus*, nor the factors influencing the proportion of each type in its diet. Data concerning the chemical composition of separate elements of the plankton are very meager, since analyses have been made on mixed catches, part of which may be unavailable for a particular species of animal. The effect of starvation upon the metabolic rate of *Calanus,* and the effect of environmental condition upon the filtering rate of this copepod are also unknown.

SUMMARY

Calanus which had been rendered practically sterile by a system of washing failed to moult when placed in sterile Berkefeld-filtered sea water but remained alive for about two weeks. The introduction of bacteria even in high concentration did not enable the copepods to moult. Rough calculations indicate that the concentration of bacteria in the sea is much too low to satisfy the nutritional needs of *Calanus.*

Calanus was found to live and moult in sea water from which the larger planktonic organisms had been removed by a paper filter, although it throve better in unfiltered water. Whether this difference was caused by qualitative or quantitative differences in the food supply has not yet been determined.

Preliminary measurements on the rate of filtration of *Calanus* gave a result less than that calculated to be necessary for the copepod to obtain sufficient food if diatoms and peridinians are the sole source of supply. Since bacteria cannot be regarded as an important source of food, the other small and little known elements of the nannoplankton should be scrutinized, as their abundance in the sea may be greater than previously supposed.

Acknowledgment

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Contribution No. 94

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THE BIOLOGY OF PSEUDOCALANUS MINUTUS IN THE GULF OF MAINE AND BAY OF FUNDY

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Introduction

The present paper forms the second of a series on the biology of zoöplankton species in the Gulf of Maine and Bay of Fundy, with special reference to production and dispersal. As in the case of *Calanus finmarchicus* (Fish, 1936) there have been two objectives; first, a determination of breeding seasons, annual number of broods, and rate of growth; second, an evaluation of different spawning areas and dispersal of eggs and larvæ. For a description of the area covered, location of stations and methods, the reader is referred to the aforementioned report. The studies were carried on between July 28, 1931 and September 29, 1932 for the International Passamaquoddy Fisheries Commission.

Regional Distribution of the Adult Stock[2]

Pseudocalanus minutus was found by Bigelow (1926, pp. 276–277) to be nearly as universal as *Calanus* in the Gulf of Maine, distributed indifferently in the coastal zone, the deeper parts of the basin, and on offshore banks. It was somewhat more nearly universal close along shore but the numbers actually present averaged larger in the basin, entrant channels, and along the offshore slope. In 1931 and 1932 it was found generally distributed in both neritic and offshore waters.

Being more indifferent to neritic environmental factors than *Calanus* and with an apparently somewhat greater thermal range, *Pseudocalanus* occurs to some extent throughout the year in inshore waters north of Cape Cod. However, like other boreal arctic species, its numbers decline rapidly with rising summer temperatures in shallow areas, and offshore Bigelow (Ibid., p. 277) observed that there is a general tendency to leave the uppermost stratum in April and May.

In Passamaquoddy Bay in 1932 there was a decline in the relative percentage of *Pseudocalanus* from 84.7 per cent on June 20 to 2.8 per cent on July 30, with a corresponding reduction in the volume of plankton from 26.7 cc. to 1.9 cc. Later it rose again to 12.1 per cent accompanied by an increase in volume to 13.3 cc. on September 23. McMurrich's unpublished data from St. Andrews in 1916 accord with these results.

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[1] Contribution No. 94.

[2] "Adult stock" includes late copepodites (for the most part stage V) appearing in the coarse net hauls.

In Frenchmans Bay, *Pseudocalanus* remains throughout the summer as one of the most important members of the zoöplankton community in the cold bottom water, but its center of abundance was found by day at a slightly higher and warmer level than that of *Calanus*.

South of Cape Cod *Pseudocalanus* largely disappears from the neritic zone during the summer months. In the Woods Hole region it remains abundant until May, declines rapidly in June after the water mass rises above 15° C., and disappears at about 20° C., reappearing usually in October (Fish, 1925, Fig. 45). *Calanus* occurs only during the coldest months in this area and is rarely ever numerous. Farther south in Chesapeake Bay *Pseudocalanus* is regularly found in the inner bay in the spring, but *Calanus* appears to be confined to the outer bay, where it is taken only in winter (Wilson, 1932, p. 13).

It would appear, therefore, that *Pseudocalanus* regularly outnumbers *Calanus* in observed neritic localities south of Cape Cod, and north of the Cape a similar condition occurs occasionally in some coastal areas during the early summer.

Production and Dispersal of Eggs and Larvæ

Spawning Areas

The distribution of eggs and early nauplii in 1931 and 1932 indicates that *P. minutus* spawns throughout the Gulf and Bay of Fundy. Even in neritic areas such as Passamaquoddy Bay where no evidence of *Calanus* propagation was found, 2,847 *Pseudocalanus* eggs per minute were taken on June 20, and 760 per cubic meter at the end of July in 1932.[3]

There is, however, considerable variation in the extent of propagation in different parts of the region. If the *Pseudocalanus* population in the inner Gulf and Bay originated largely in the western coastal area, as appears to be the case with *Calanus,* one would expect the quantitative distribution of larvæ of the two species to be very similar. The data obtained in 1932 indicate striking differences. Whereas the numbers of *C. finmarchicus* in all stages declined uniformly to the eastward (Fish, 1936, Fig. 11) and quantitative fluctuations in the western area were reflected throughout the region, in *P. minutus* the number of larvæ in the eastern basin and particularly in the outer part of the Bay of Fundy was usually as large or even larger than west of Mt. Desert (Fig. 1).

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[3] Just outside of the bay in outer Quoddy waters (Sta. 5) *Calanus* eggs totalled 7,608 per minute and *Pseudocalanus* 37,018 on June 20, and *Calanus* 710 per cubic meter and *Pseudocalanus* 800 on July 30.

This condition could have resulted either from intensive local spawning or large contributions from other areas. In regard to the first possibility, evidence of immigration in the horizontal distribution of all advanced larval stages of *P. minutus* indicates that production of this species in the eastern coastal region is on the whole probably no more successful than that of *C. finmarchicus* (Ibid., p. 140), *Sagitta elegans* (Huntsman and Reid, 1921, p. 110), and fishes having pelagic eggs (Bigelow, 1926, pp. 70–73; Huntsman, 1918, p. 65, 1922). Considering other possible sources of supply, as propagation in the western coastal area does not seem to have been sufficient to account for the increasingly large numbers of *Pseudocalanus* occurring farther east (up to 215,698 late nauplii per minute in the Bay of Fundy in June) as the season advanced (Fig. 7*B*), it is probable that the principle spawning area of *P. minutus* is located in the outer Gulf where Bigelow (1926, p. 277) regularly found the species most abundant. The western coastal area appeared to be an important source for the first brood (Fig. 5*A*) in 1932, but thereafter declined until in mid-August there was little evidence of appreciable propagation except in a restricted locality represented by the innermost stations between Casco and Penobscot Bays (Figs. 8*A* and *B*).

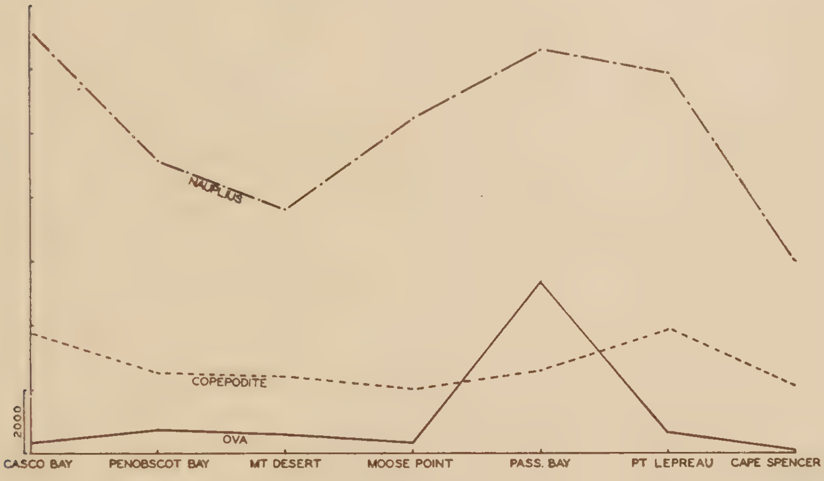

FIG. 1. Mean numbers of ova, nauplius and copepodite stages of *P. minutus* per minute of towing for the period April–July, 1932.

Breeding Seasons

The breeding periods of *P. minutus* appear to be somewhat similar to those of *C. finmarchicus.* As in the latter species, propagation begins earlier in the southern portion of its range and there appear to be a greater number of annual broods.

South of Cape Cod *Pseudocalanus* enters neritic waters in late October and breeding must soon follow because in 1922–23 early copepodite stages appeared at Woods Hole by the middle of December (Fish, 1925, p. 144). A maximum of copepodites in January was followed by a rise of adults in February. A second brood of less importance appeared in March and April. Some no doubt enter the region from the north where vernal augmentation takes place at this time, but in view of the abundance of adults at Woods Hole in February, it seems probable that the greater part of the March–April copepodites were of local origin. With the rise in temperature in May the numbers declined, and the species practically disappeared from inshore waters in June. Subsequent broods no doubt occur offshore where *Pseudocalanus* is found throughout the summer. The southern limit of successful propagation is not known but its presence regularly in Chesapeake Bay in winter and spring (Wilson, 1932) would suggest that there may be some successful spawning at that latitude during the cold months.

North of Cape Cod, Willey (1918, p. 187) reported females with eggs and attached spermatophores in August, and Bigelow (1926, p. 282) concluded that " the seasonal fluctuations in the numerical strength of the stock point to breeding as taking place most actively from June until September and to the entire gulf as its site."

Ruud's records (1929, pp. 67–68) indicate that the cycle in Norwegian waters is somewhat similar to that of *C. finmarchicus.* Spawning begins in March off Möre and probably earlier off the west coast of Norway. In 1926 there was a maximum of copepodite stages I–III on April 28–29. All copepodite stages had another maximum on July 20. This would suggest production in March, the young reaching maturity in May–June and the second generation attaining copepodite stages by July 20. Several observers have reported the presence of copepodite stages and mature adults in northern waters during the summer (Störmer, 1929, p. 31; With, 1915, p. 61; Bogorov, 1932).

In the Gulf of Maine and Bay of Fundy the seasonal distribution of young stages in 1931 and 1932 indicates that propagation begins in March and continues in a succession of generations throughout the region until September.

Regional variation.—Eggs of *P. minutus* appear at progressively later periods in the outer Gulf, western area, and Bay of Fundy, and, on the basis of this regional variation in the time of spawning, it is possible to distinguish three major breeding stocks.

These stocks are not permanently restricted to their respective localities, but merely represent delayed maturation of that portion of the winter population of *P. minutus* which happens to be located in the eastern part of the Gulf and Bay of Fundy during the spring, and earlier maturation in areas to the westward where the water mass responds more rapidly to vernal warming.[4] This is evident from the fact that the progeny of all stocks disperse and appear to become established over much if not all of the region, and also because within a region with a dominant drift it would be impossible to have permanently localized zoöplankton stocks without bottom stages. From the surface to the bottom the plankton population in any part of the open Gulf and Bay is in varying degrees a transient one. However, since the annual cycle in the three major areas starts at different times, with approximately the same interval of development (p. 200), one would expect the distinct breeding periods of the three stocks to be continued, as in *Calanus* (Fish, 1936, p. 130), in subsequent generations no matter where they might be dispersed. This is indicated in the present material.

In the following pages symbols will be used to designate the different stocks originating in the three general regions in the spring, and their respective progeny wherever distributed during the remainder of the season: *A* indicating the outer gulf stock, *B* that of the western coastal area, and *C*, that originating east of Mt. Desert in the inner Gulf and centered in the Bay of Fundy.

Annual Cycle in Different Breeding Stocks

Tracing the succession of broods in the three breeding stocks of *P. minutus* is more complicated than in *C. finmarchicus*. Unlike the latter species, where the bulk of the population of the Gulf apparently originates in one area (western) and can easily be traced, the broods of *P. minutus* are everywhere so largely depleted before copepodite stages are reached, that the particular stock which happens to be in early larval stages at the time dominates throughout the Gulf and Bay. Copepodite stages were almost always relatively sparse and in the present collections rarely formed appreciable maxima.

Since the succession of generations is most clearly defined in the stock maturing in the western coastal region in the spring, this stock (*B*) will be considered first. There appear to be at least three and possibly four breeding periods: March–April, May–June, July–August, and September. As seen in the quantitative distribution in successive

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[4] It is probable that the transfer of adults from one area to another is relatively much slower than that of larvæ because, by descending during the daylight hours, they pass beyond the influence of the surface into a slower dominant drift.

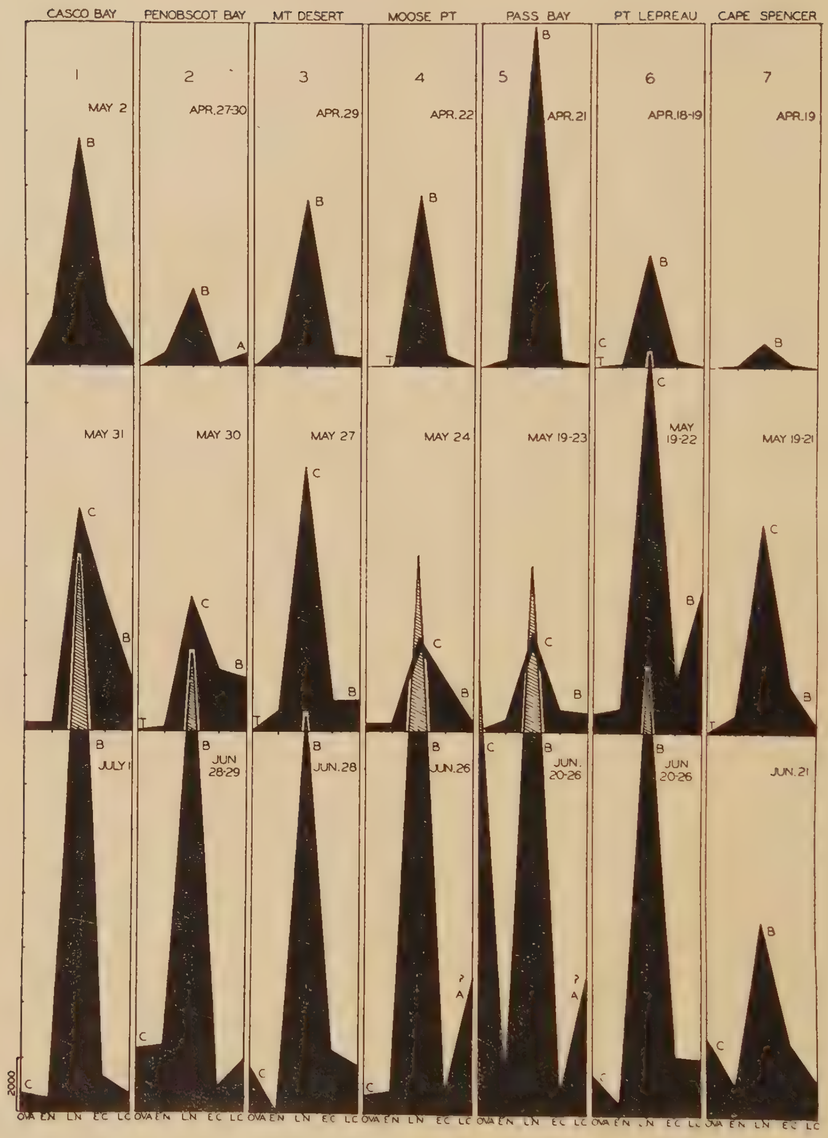

FIG. 2. Changes in the composition of the population of *Pseudocalanus minutus* (developmental stages) in seven sections between Casco Bay and Cape Spencer from April to June, 1932. Number per minute of towing. Stages recorded as: ova, early nauplii (I–III), late nauplii (IV–VI), early copepodites (I–III), and late copepodites (IV–V). *B* indicates stock originating in the western area in the spring, *C* indicates that of the eastern Gulf and Bay of Fundy, and *A*, the outer Gulf stock. *T*—trace.

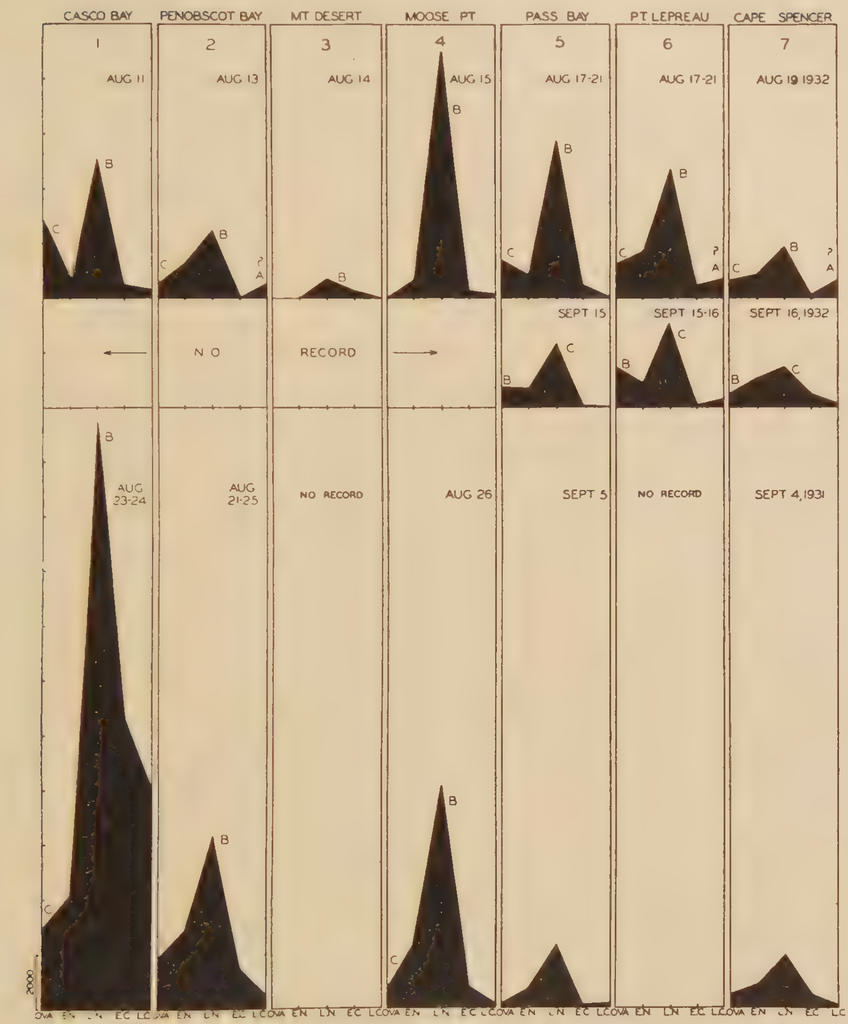

FIG. 3. Composition of the population of *Pseudocalanus minutus* (developmental stages) in August and September, 1931 and 1932. Number per cubic meter. Stages and symbols as in Fig. 2.

months, the first brood in advanced nauplius stages in late April had reached late copepodite stages on May 19–22 (Fig. 2, Section 6), and mainly completed the final moult by May 31 (Section 1). What is assumed to have been the second and largest western brood was represented by a maximum of late nauplius stages in the latter part of June. It would thus appear that the cycle during the early season is completed in about 60 days. The third brood, hatching on July 30 (Fig. 4), probably developed somewhat more rapidly with warmer summer temperatures and attained late nauplius stages by mid-August in the western area (Fig. 3). Even in the eastern Gulf at lower temperatures a large part of this stock passed from early to late nauplius stages between August 8 and 15, as indicated in Table I. Eggs entering the Bay of Fundy on September 15–16 would suggest a fourth generation but further data from the Gulf at this season are needed. It seems probable that a considerable percentage of the third crop remains in late copepodite stages to form the winter stock.

TABLE I

Stage	August 8, Sta. 15	August 15, Sta. 33
Egg	1,132	
Early nauplius	4,335	565
Late nauplius	5,842	12,060
Early copepodite	1,695	565
Late copepodite	377	377

In stock C, originating in the eastern area, there is evidence of three breeding periods: April–May, June–July, and August. Local propagation was just beginning in the Bay of Fundy on April 19 (Fig. 2, Section 6) and a month later nauplius stages dominated. With a cycle of 60 days, eggs on June 20 (Fig. 4) would represent a second brood which by August 11–21 had matured and were spawning (Figs. 3 and 8*A–B*). A third brood is indicated by a maximum of late nauplius stages in the Bay of Fundy on September 15 in 1931 (Fig. 4), and September 15–16 in 1932 (Fig. 3).

Some less definite indications of a possible succession of generations in stock *A* after April are to be found in the data from the coastal region and the Bay.[5] In 1932, on June 20–26, when stock *B* was mainly in late nauplius stages, and the second brood of eggs of stock *C* had just appeared, a smaller maximum of late copepodite stages (Fig. 2, Sections 4 and 5) in the eastern basin may have represented a second brood of immigrants from offshore (Fig. 9*A*). With a developmental period of two months this would be expected. There is also an indication of a third crop of late copepodites on August 11–21, particularly in the western area (Fig. 3, Section 2) and the Bay of Fundy (Sections 6 and 7), but the numbers are too small to be of any real significance (Fig. 9*B*).

Although there was no detectable trace of stock *A* in May (Fig. 2), on the basis of the developmental period, the succession of subsequent maxima just described would appear reasonably indicative were it not for another complicating factor—the relatively small numbers of progeny attributable to this stock. There appears to be no logical reason for the depletion of one breeding stock of *Pseudocalanus* and the survival of another in the same locality. It is probable, therefore, that following the first generation of stock *A*, due to overlapping spawning periods, subsequent broods of this stock and stock *C* cannot with certainty be distinguished. At least a part of stock *A*, in copepodite stages in the outer Gulf on April 11–12 (Fig. 5*B*), would be expected to have matured and started to spawn by the time eggs, forming the first brood of stock *C*, appeared in the Fundy region in the latter part of the month. In this case subsequent maxima, appearing in each instance one month after maxima of similar stages of stock *B*, would represent the combined stocks *A* and *C*, and the maxima of late copepodite stages[6] in late

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[5] In *Calanus,* either spawning in the outer gulf and western area coincides or the number of individuals of the offshore stock is insufficient to exert a detectable effect on the larval population of the inner gulf and bay.

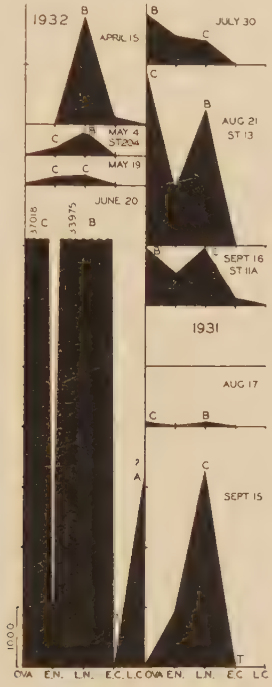

FIG. 4. Composition of the population of *P. minutus* in developmental stages at Station 5 (unless otherwise noted) in the New Brunswick area of the Bay of Fundy, showing the succession of generations of the (*B*) western, (*C*) eastern, and (*A*) outer Gulf stocks. *T* indicates trace. April–June: number per minute. July–September: number per cubic meter.

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[6] These copepodites, according to this interpretation, were probably derived from eggs appearing near the end of the previous spawning period and might be indicative of either one or both stocks.

June and August should be grouped with eggs appearing at the time. Further evidence in support of this contention will be presented later (pp. 209–211). In any event, with a similar rate of growth, it is reasonable to conclude that in stock *A* there are four broods, each of which appears about a month earlier than in stock *B* and two months or approximately one generation in advance of stock *C*.

Annual variation.—Observations at corresponding stations were made approximately two weeks later in 1931 than in 1932. As in the case of *Calanus* (Fish, 1936, p. 130) the season appeared about equally advanced in the western area, the slight increase in the percentage of copepodite stages off Casco Bay in 1931 (12 days later) being expected (Fig. 3).

In the central area east of Mt. Desert, and the Bay of Fundy, the fact that the relative numbers in comparable stages were approximately the same in the two years, would indicate that in 1931 the season was delayed about two weeks, a condition also according with *Calanus* (Ibid., p. 130).

TABLE II

Stage	Central Area		Bay of Fundy	
	1931 (Aug. 26)	1932 (Aug. 8–15)	1931 (Sept. 1–5)	1932 (Aug. 17–21)
Egg	750	566	225	1,041
Early nauplius	2,204	1,414	800	1,091
Late nauplius	8,117	8,810	2,937	4,112
Early copepodite	799	989	275	302
Late copepodite	188	330	112	442

Mortality in Developing Larvæ

The degree of mortality in developing larvæ of *P. minutus* can best be seen by comparing the relative abundance of different stages with those of *C. finmarchicus.* Of the two species *Pseudocalanus* must be by far the more prolific. The large number of spermatophores frequently found attached to individual females (Willey, 1919, p. 187, records as many as 24) suggests high egg production. The ovisac when attached contains usually from one to three eggs, but this may prove to be an adaptation for temporarily retaining the eggs to insure fertilization. Sars (1903, p. 21) observed that the sac is so fragile that it easily becomes detached at the slightest touch, and in examining Bigelow's collections (1926, p. 281) taken throughout the period of propagation in the Gulf of Maine, Wilson failed to find a single egg-bearing female. Individuals with from one to two attached eggs were frequently taken in 1932, but to account for the numbers of free eggs of this species present at times in the region, several hundred must be produced by each individual. During the season of 1932, as shown in Table III,

although adults (including stage V) were outnumbered by *Calanus* in the total region by an average ratio of over 4 to 1, eggs and larvæ of *Pseudocalanus* dominated at all times with an average ratio of 2.5 to 1.

TABLE III

1932	Eggs and young (all stages)		Relative percentage of adults	
Month	P. minutus	C. finmarchicus	P. minutus	C. finmarchicus
April	7,126	2,011	12.4	25.7
May	11,610	7,454	12.7	56.4
June	24,967	10,588	16.8	44.7
August	6,435	3,135	2.1	35.6
September	4,378	794	1.3	37.3

April–June: number per minute. August–September: number per cubic meter.
Relative percentage of adults (including stage V) in the zoöplankton population.

TABLE IV

Section	1932	P. minutus	C. finmarchicus
Casco Bay	April–June	17,248	13,137
	August	8,049	4,466
Penobscot Bay	April–June	12,442	9,490
	August	4,897	4,342
Mt. Desert	April–June	13,635	7,160
	August	956	1,860
Moose Peak	April–June	12,834	3,679
	August	10,181	5,184
Passamaquoddy Bay	April–June	20,494	4,749
	August–September	6,072	2,145
Pt. Lipreau	April–June	16,424	6,873
	August–September	7,164	1,516
Cape Spencer	April–June	8,893	1,665
	August–September	3,813	578

April–June: number per minute. August–September: number per cubic meter.

This is seen in Table IV to occur everywhere in the inner Gulf and Bay, the differences being greatest east of Mt. Desert.

Unlike *Calanus,* in which the depletion appears to be most extreme following the final moult (Nicholls, 1933, p. 95; Fish, 1936, p. 136), the decline in *Pseudocalanus* seems to be greatest in late nauplius stages.

There must also be a second critical period during maturation, which affects a far greater percentage of the stock than in *Calanus,* to establish the adult ratio because copepodite stages of *Pseudocalanus* exceeded those of Calanus during both the early and late summer seasons. (See Table V.)

Physical environmental factors appear to offer no logical cause for the depletion throughout the Gulf and Bay, and in the case of the late nauplii it seems to be attributable to destruction by enemies. Were there a lack of food, the relative decline in *Calanus* and *Pseudocalanus* larvæ would be expected to be similar.

Dispersal and Result on Regional Abundance of the Stock

The dispersal of eggs and larvæ from production centers and subsequent distribution of the adult stock are largely dependent on non-tidal circulation. The surface drift in the Gulf of Maine is counter-clockwise, eddying around a central vortex. Eggs and larvæ produced in the western area would tend to be transported offshore and eastward around the outer margin of the Gulf. Outflow around the eastern end of Georges Bank as well as past Cape Cod would carry some of the larvæ, particularly those near the periphery of the drift, out of the region. However, an appreciable portion of the migrant stock or its progeny would be expected to remain within the Gulf completing the circuit across the entrance of the Bay of Fundy and westward along the coast of Maine, and some would continue eastward into the Bay along the Nova Scotian side.

Table V

Total region 1932	April–June (Mean number per minute)		August–September (Mean number per cubic meter)	
Stage	P. minutus	C. finmarchicus	P. minutus	C. finmarchicus
Nauplius	10,568	2,160	4,476	638
Early copepodite	1,468	1,103	230	48
Late copepodite	1,079	514	292	10

One would therefore expect to find larvæ from the western area circling the outer Gulf and, with contributions from the latter area, supplementing the stock in the eastern basin and Bay of Fundy. Similarly, the greater number of eggs and larvæ originating in or entering the Fundy region would, if they survived, leave the Bay in the outflow which passes east and south of Grand Manan and tend to be dispersed westward in the inner gulf.

Dispersal in 1932.—Dispersal of individual stocks through successive generations has been traced by the monthly changes in the distribution of larvæ. Although stages ranging from ova to adults could usually be found almost everywhere in the region at any time, the maximum numbers, particularly of stock *B*, were in stages sufficiently separated from those of the other stocks to permit detection (Figs. 2 and 3).

Stock B.—Late nauplius stages, representing the first brood of that portion of the *P. minutus* population located in the western Gulf in the spring, were widely distributed throughout the region with local concentrations in the western and eastern basins by late April (Fig. 5*A*). A considerable part of the parent stock must have been transported well around the outer Gulf before spawning to account for such large numbers of nauplii in the Fundy region. There is a possibility, of course, that the larvæ might have been locally produced, but the sparseness of earlier stages east of Mt. Desert in the inner Gulf (Figs. 2 and 3) at this time and the appearance later of a distinct eastern brood (p. 200) warrants the conclusion that they were derived from parents transported from the western Gulf.

The concentration of late nauplii in a limited area off Halifax (Fig. 5*A*) indicates that the season, as in the case of *Calanus* (Fish, 1936), was as far advanced there as in the western coastal region. In the intervening region late nauplii were not found numerous until May, a condition somewhat comparable with the Bay of Fundy.

From April to May stock *B* declined greatly in numbers and by the time late copepodite stages were reached at the end of the latter month, quantities in excess of 1,000 per minute were found only in the inner Gulf west of Mt. Desert and over the central basin of the Bay of Fundy (Fig. 6*C*). The latter were no doubt migrants from the western or outer Gulf because copepodites were still very sparse as far west as Mt. Desert in the path of the outflow from the Bay, where one would have expected to find the stock present in the Fundy region in April if it had survived.

By the end of June important changes in the picture were noticeable. The second brood of stock *B* in late nauplius stages was, like the first brood in May, centered in the western coastal area and Bay of Fundy. In view of evidence of unsuccessful production in the latter area (p. 195), and the large number (21,410) of late nauplii in the entering drift on the Nova Scotian side, it seems probable that the April brood of stock *B* had become established in the general region of Georges Bank and the second brood of migrant larvæ from the western area were now being supplemented by increasingly large contributions from the outer Gulf. It was at this time (June 21) that the immense swarm mentioned on page 195 was encountered off St. John (Fig. 7*B*).

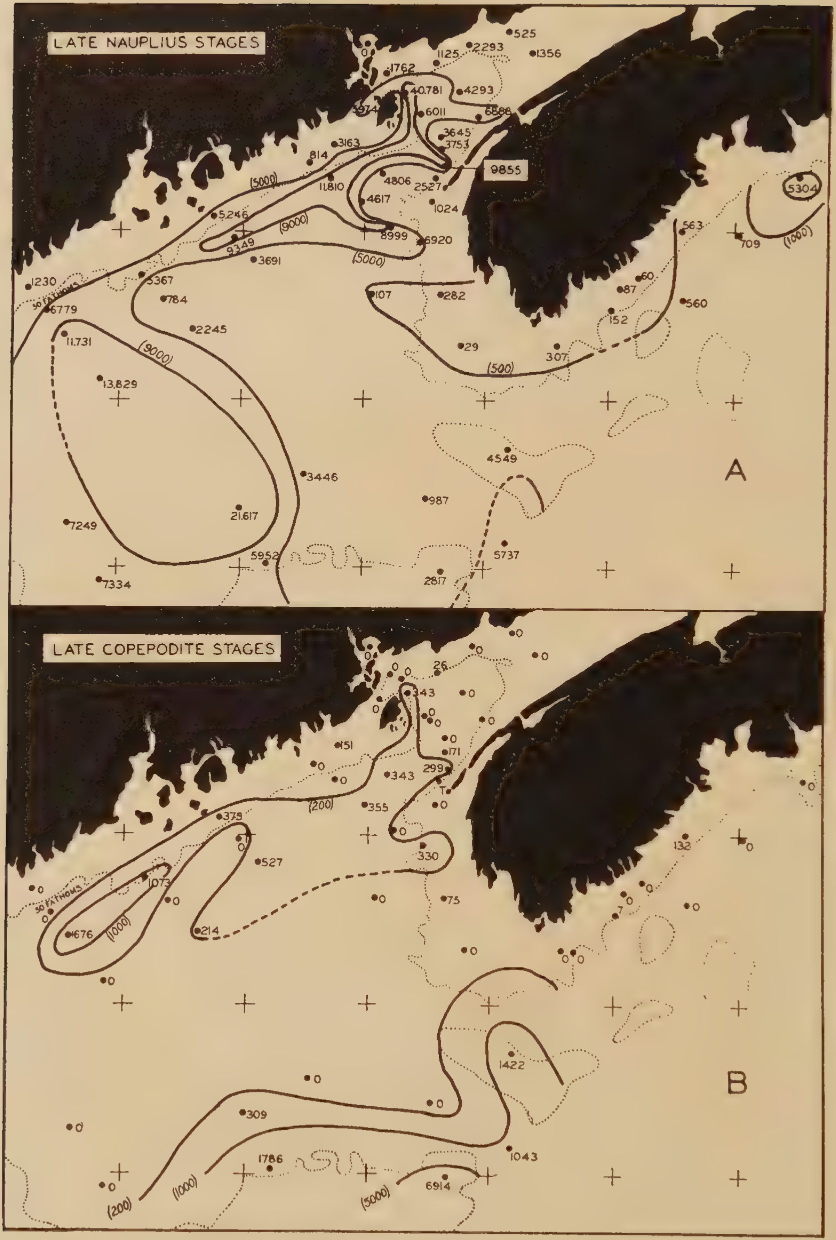

FIG. 5. Occurrence of late nauplius stages (*A*) of the western stock, and late copepodite stages (*B*) considered indicative of offshore propagation, in April, 1932. Number per minute of towing.

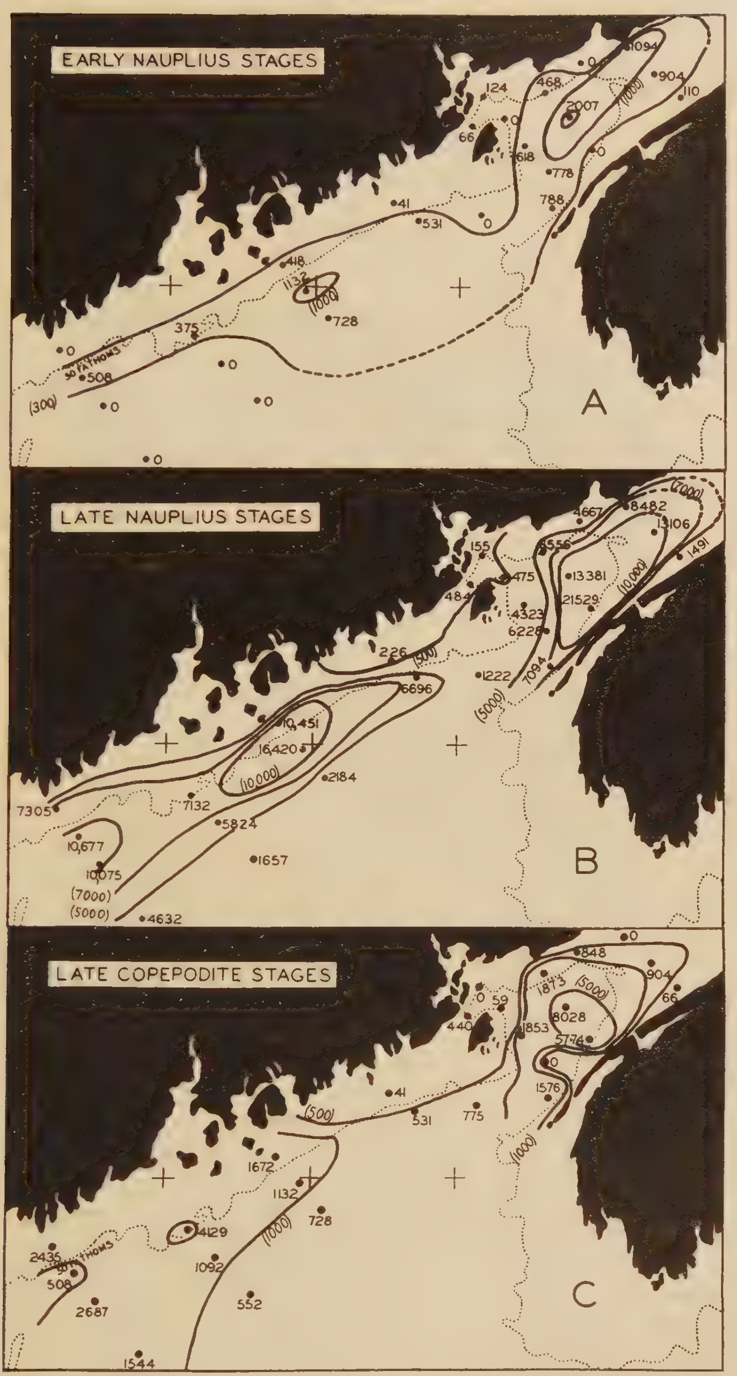

FIG. 6. Occurrence of nauplius stages (*A–B*) of the eastern stock, and late copepodite stages (*C*) of the western stock in May, 1932. Number per minute of towing.

There can be no doubt that by mid-August the larger part of the *P. minutus* population was originating in offshore waters. The third brood of stock *B*, by this time in late nauplius stages (Figs. 3 and 4), was, in the inner Gulf, definitely centered in the eastern basin and along the Nova Scotian side of the Bay of Fundy (Fig. 8*C*). Immigration of this population from the outer Gulf is indicated by the continued scarcity of larvæ in the New Brunswick area and the coastal zone of eastern Maine beyond the immediate influence of the drift. The stock in the western area had declined until only at the innermost station off Casco Bay were more than 5,000 late nauplii per cubic meter taken.[7] If these conditions can be considered normal, then once the first brood of the stock originating in the western area in April becomes dispersed throughout the region, a considerable portion of the second brood, and

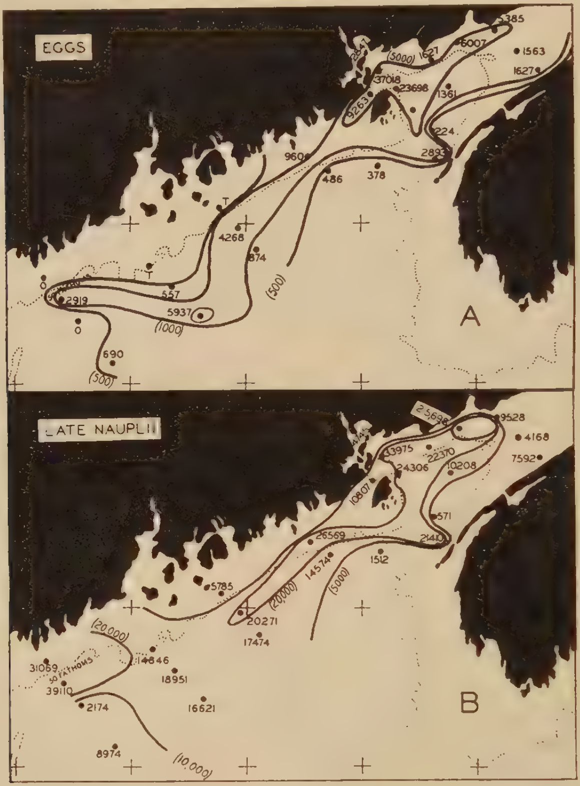

FIG. 7. Occurrence of eggs (*A*) of the second eastern brood and late nauplii (*B*) of the second western brood in June, 1932. Number per minute of towing.

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[7] Possibly the large population of predatory plankton animals in this region in summer depletes the *P. minutus* larval stock.

the greater part of the third, are derived from individuals establishing themselves in the general region of Georges Bank.

Autumn dispersal in the Gulf could not be traced as observations were restricted to the Bay of Fundy after August. By September both eggs (presumably the fourth brood of stock *B*) and larvæ of *P. minutus* had declined greatly in the Bay.

Stock C.—Originating from that portion of the *P. minutus* winter population maturing in the eastern Gulf and Bay of Fundy, stock *C* is believed to have been represented by small numbers of eggs at Station 37 in the Bay on April 20. Vernal augmentation must have just begun because eggs were not found elsewhere in April.

Differing from stock *B*, in which maturing adults of the parent stock had apparently become widely dispersed in the Gulf before spawning (Fig. 5*A*), propagation of the first brood of stock *C* seems to have been largely if not entirely restricted east of Mt. Desert. By May 18–24 late season eggs were not found outside of the Bay of Fundy;[8] early larvæ occurred at but two out of seven stations in the western area (Fig. 6*A*), and late nauplius stages (Fig. 6*B*), although more widely dispersed, were centered in the Bay of Fundy and along the course of the coastal drift from the eastward. It is probable that these late nauplii originated in the eastern basin and not in the Bay of Fundy because in the latter area the largest numbers were found in the course of the entering drift. Indicating local conditions beyond the immediate influence of this inflow, there was little evidence of survival in New Brunswick and eastern Maine coastal waters (Fig. 6*B*).

An analysis of the dispersal and resulting regional abundance of subsequent generations of this stock is rather complicated. Apparently the large numbers of late nauplii entering the western area in May (Fig. 6*B*) failed to establish themselves, for when this brood matured and were spawning in late June (Fig. 2) the numbers of eggs everywhere west of Mt. Desert were relatively small and at several of the stations none were found (Fig. 7*A*). This may have been due to destruction by enemies as previously suggested (p. 208) because the rich local population of plankton animals was at its maximum, and, as shown by conditions in August (Fig. 8), all of the breeding stocks of *P. minutus* were rapidly depleted in that area. On the other hand, corresponding to this decline in the western Gulf, there was a surprising increase of adults and eggs in the Bay of Fundy in late June. In the New Brunswick area adult *P. minutus* formed up to 83.2 per cent of the total zoöplankton population (Table VI, p. 213) and eggs up to 33,975 per

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[8] Eggs, up to 1,405 per minute on May 19, were found only along the New Brunswick coast where the season appeared more retarded than elsewhere in the eastern region.

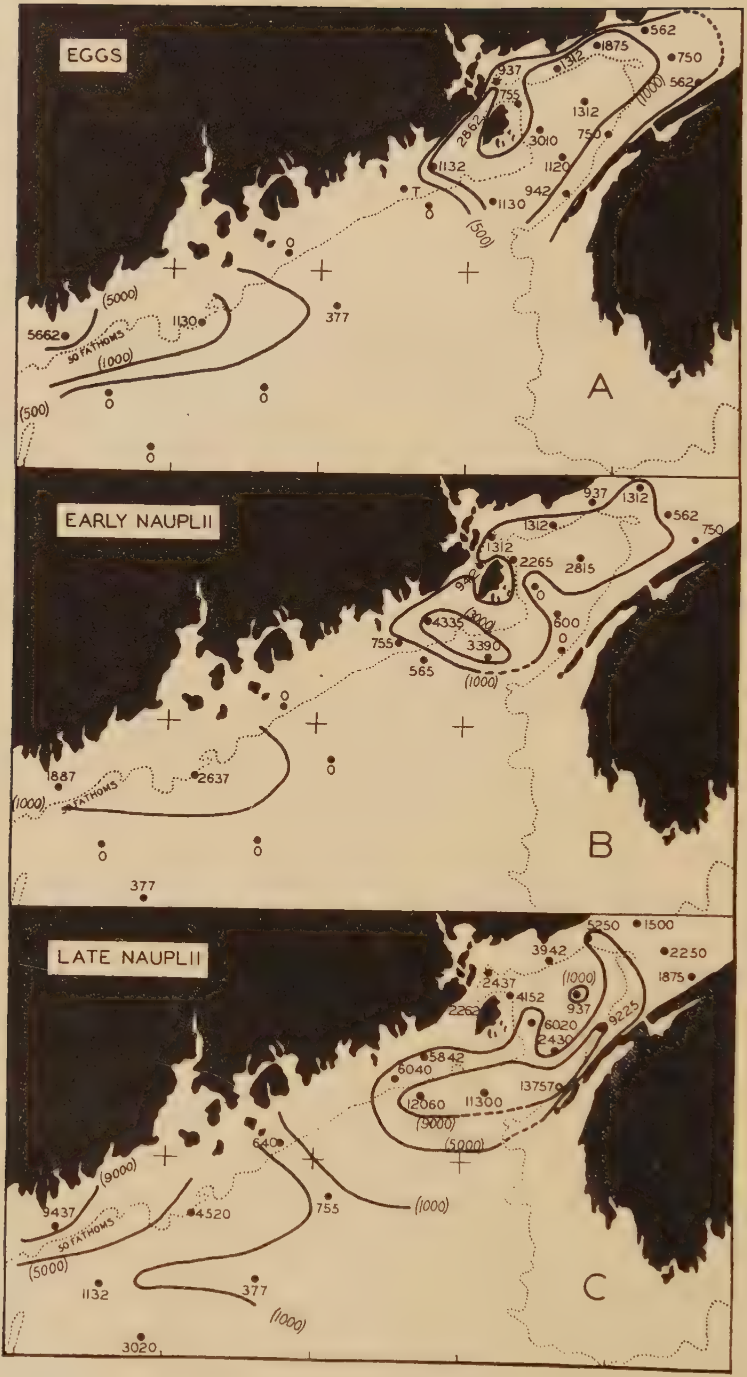

Fig. 8. Occurrence of eggs and early nauplii (*A–B*) of the third eastern brood and late nauplii (*C*) of the third western brood in August, 1932. Number per cubic meter.

cubic meter (Fig. 7*A*). The source of this population is somewhat uncertain, but, in view of the above-mentioned evidence of unsuccessful local production, it is believed that the adults consisted partly of members of the first brood of stock *C* from the eastern basin of the Gulf, and partly of the second brood of stock *A* from the outer Gulf (pp. 201–202). It is barely possible that propagation of this species is nowhere successful in the eastern Gulf and that all subsequent broods attributed to stock *C* were in reality migrants of stock *A*. This seems unlikely, however, since late nauplii off Mt. Desert in May (Fig. 6*B*) could hardly have been produced much farther away than the eastern basin.

By August further changes became evident. Eggs and early nauplii, presumably of the third brood of stock *C*, were concentrated in the Fundy region (Fig. 8*A* and *B*) and their scarcity or complete absence for some distance eastward from Mt. Desert would indicate that the depletion of the *P. minutus* population had now extended from the western Gulf to include the eastern basin. The similarity in the distribution of the two stocks, *B* (Fig. 8*C*) and *C* (Fig. 8*A* and *B*), in the Fundy region in August is most readily explainable on the basis that both were now centered in the same locality, and that the larvæ were derived from parents transported from the general vicinity of Georges Bank. Had observations been continued in September, it might have been possible to determine whether, with the decline of the predatory animal population, there occurred a progressive restocking to the westward in the inner Gulf by these migrants from offshore or their progeny. There is some indication that this may occur in Bigelow's (1926, p. 281) observation that there is "a greater absolute abundance over the area as a whole in late summer and autumn." Within the Bay of Fundy in mid-September, late nauplius stages of stock *C* (third brood) were most numerous (3,563 per cubic meter) in the entering drift from the Gulf and over the central basin.

Stock A.—Little can be said about the dispersal of this stock after April because of the probable confusion with stock *C* (p. 201). Originating offshore in March, by late April the larvæ, in late copepodite stages, were centered in the region of Georges and Browns Banks. Along the probable course of the drift smaller numbers had been dispersed to the outer part of the Bay of Fundy and along a tongue-like band penetrating the western area.

If copepodites in late June and August (p. 202) can be considered to consist in part of stock *A*, then this stock in the inner Gulf, at all times in the summer of 1932, remained restricted largely to the eastern basin and Bay of Fundy. One would have expected to find the progeny of the first brood (entering the western area in April) generally dispersed throughout the western Gulf, but the distribution of all copepodites in June (Fig. 9*A*) and again in mid-August (Fig. 9*B*) clearly indicated migration from the eastward.

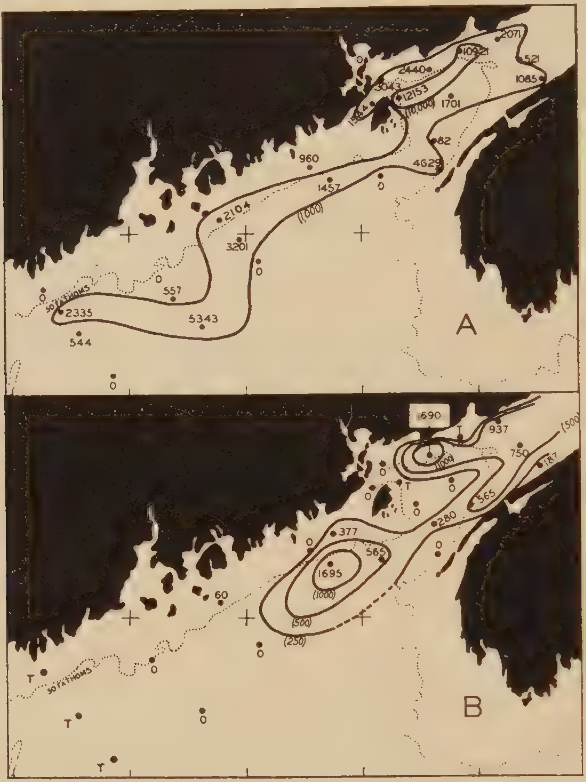

FIG. 9. Occurrence of late copepodite stages considered indicative of the outer Gulf stock in June (*A*) and August (*B*), 1932. June: number per minute of towing. August: number per cubic meter.

RELATIVE NUMERICAL STRENGTH OF PSEUDOCALANUS MINUTUS (ADULTS) IN THE ZOÖPLANKTON POPULATION

In the Gulf of Maine and Bay of Fundy *Pseudocalanus minutus* is second only in importance to *Calanus finmarchicus*. Offshore it is usually far outnumbered by the latter species, but in inshore waters such as the Quoddy region (Sta. 5, Table VI) and bays in the Gulf it is at times the dominant form. A similar condition is also found in the coastal region south of Cape Cod (Fish, 1925, p. 144, Fig. 45), and to the northward in the Gulf of St. Lawrence where Willey (1919, p. 187) found it constituting between 80 and 90 per cent of the copepod content between Prince Edward Island and the Magdalen Islands in May, 1915.

Combining the results of several years in the Gulf of Maine, Bigelow (1926, p. 282) found that *Pseudocalanus* averaged about 11 per cent of the copepod stock and as a rule was from one-tenth to one-fifth as abundant as *Calanus.* In 1932 during the period from April until September *Pseudocalanus* averaged 4.9 per cent of the total zoöplankton population of the Gulf, and *Calanus* 42.9 per cent, a ratio falling within Bigelow's range.

In the Bay of Fundy, based on monthly averages for three stations, the mean percentage of *Pseudocalanus* in meter net hauls for the year ending in August, 1932 was approximately 10, as shown in Table VI.

TABLE VI

1931–1932	*Pseudocalanus minutus*			
Month	Mean	Sta. 5	Sta. 6	Sta. 8A
September	2.3	3.7	2.8	0.5
October	1.5	1.5	——	——
November	1.9	2.1	3.3	0.3
December	3.1	4.5	2.3	2.5
January	8.2	8.2	——	——
March	12.0	6.6	10.9	18.5
April	5.8	5.5	5.8	6.0
May	22.0	53.2	8.0	4.8
June	43.4	83.2	45.2	1.7
July	3.0	3.0	——	——
August	5.3	15.2	0.8	0
Mean for Year	9.9	17.0	9.9	4.3

Along the New Brunswick shore (Station 5) it formed a much more important part of the plankton population than over the central basin or along the Nova Scotian side. Whereas *Calanus* increased in a seaward direction from the New Brunswick coast, the relative percentages of *Pseudocalanus* for the year decreased from 17 per cent in the Quoddy region to 4.3 per cent at the entrance to the Bay (Station 8*A*). This condition remained constant except for a short period following vernal augmentation when the percentage was greatest in the path of the drift from the Gulf. The highest value in the Bay (83.2 per cent) was found in the outer Quoddy region in June.

During the summer (April–September) the relative percentage of *Pseudocalanus* decreased westward from the Bay of Fundy, averaging 17.2 per cent in the Bay and as previously mentioned, 4.9 per cent in the Gulf, with minimum values in the western area.

Monthly averages indicated a definite seasonal variation in all areas covered in 1932 as the summer advanced. The highest value for the western area (10.6 per cent) was in April, for the central area (12.5 per cent) a month later in May, and for the New Brunswick area (59.2 per cent) in June. These results reflect the progressive response to vernal augmentation eastward along the coast. Indicating immigration from the western and outer Gulf, the Nova Scotian area yielded the highest percentages in March and April. Almost everywhere there was a continued decline after the first maximum, in spite of subsequent propagation.

The importance of *P. minutus* in the natural economy of the region is obviously greater than the relative numerical strength of the adult population would imply. Although, as Bigelow (1926, p. 282) has pointed out, the adult stock is still far behind *Calanus* because of its smaller size and fewer numbers, the enormous number of larvæ produced and subsequent rate of depletion indicate that its importance to those small predatory forms (including several of the more important species of Gulf fishes during their early existence) feeding on larval copepods must be considerably greater in some parts of the region than that of *Calanus*.

Table VII

1932			Gulf of Maine			Bay of Fundy		
Cruise	Month	Total region	Total gulf	Western area	Central area	Total bay	New Brunswick area	Nova Scotian area
26	April	12.4	7.9	10.6	5.2	21.5	29.0	14.4
27	May	12.7	8.1	4.3	12.5	21.4	34.3	6.4
28	June	16.8	7.3	3.5	11.7	35.3	59.2	7.5
30	August	2.1	1.0	0.7	1.4	4.3	4.8	3.7
32	Sept.	1.3	0.1	0.3	T	3.6	2.1	5.1
Mean	April–Sept.	9.1	4.9	3.9	6.2	17.2	25.9	7.4

Summary

1. *Pseudocalanus minutus* is generally distributed both in neritic and offshore waters. Having a somewhat greater thermal range it regularly outnumbers *Calanus* in neritic areas south of Cape Cod and on occasions in boreal waters also.

2. Propagation begins in March and continues in a succession of generations until September. It starts earlier in the southern part of the range where there are also a greater number of annual broods.

3. Eggs appearing at progressively later periods (approximately monthly intervals) in the outer Gulf, western area, and Bay of Fundy make possible a distinction of three major breeding stocks.

4. In the western stock there are at least three and possibly four breeding periods, March–April, May–June, July–August and September.

5. In the eastern stock there is evidence of three breeding periods, April–May, June–July, and August.

6. The outer Gulf stock is not clearly traceable due to probable overlapping of subsequent breeding periods with those of the eastern stock, but four periods are indicated.

7. There appears to be a developmental period of approximately two months throughout the region.

8. *Pseudocalanus* is very prolific and its early larvæ greatly outnumber those of *Calanus.* Mortality is relatively much higher in *Pseudocalanus,* the depletion being greatest in nauplius stages, although a second critical period during maturation is indicated.

9. There is no evidence of successful propagation in the Bay of Fundy, and the western area declines in importance after the first brood. Subsequent propagation of all breeding stocks appears to be centered in the outer Gulf.

10. The adult stock of *Pseudocalanus* is second only to that of *Calanus* in numerical importance, averaging 9.9 per cent of the total zoöplankton population in the Bay of Fundy during the year 1931–32 and 4.9 per cent of the summer population in the Gulf.

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Contribution No. 95

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THE OXYGEN UPTAKE OF MARINE BACTERIA

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In recent studies from the Woods Hole Oceanographic Institution (Waksman and Carey, 1935a), it was shown that stored sea water rapidly undergoes a decrease in oxygen content, with a somewhat parallel increase in numbers of bacteria up to a maximum population level, after which oxygen decrease continues to take place in the water. The rates of bacterial multiplication and oxygen consumption were considered as indices of the availability of the organic substances present in the water, in solution and in suspension. In order to learn whether the marine bacteria of themselves could account completely for these phenomena, a study was undertaken on 25 pure cultures of organisms freshly isolated from the sea,[2] with the object of determining their rates of oxygen consumption in the "resting" condition, and the influence of temperature as well as of added organic matter of both readily and not so readily utilizable nature on these rates. Glucose, C.P., was selected as probably the most readily available substance, and purified alginic acid[3] as one less generally available. The latter compound occurs abundantly in marine algae (Waksman, Carey and Allen, 1934).

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[1] Contribution No. 95 of the Woods Hole Oceanographic Institution.

[2] All cultures were isolated and kindly supplied to the writer by Dr. S. A. Waksman. They are being carried in the collection at Woods Hole for future study, but are referred to here by number, awaiting identification or description. The limited objective of this study, as stated above, renders less important the specific name of each organism. Three of the species however, which were recently described (Waksman *et al.*, 1934), are: *Bacterium alginicum* (AA2); alginic acid bacterium No. 8 isolated from diatom tow and related to *Bacterium alginovorum* (AA8); and, *Bacterium fucicola* (AA17).

[3] Prepared and kindly furnished to the writer by Dr. S. A. Waksman.

In order to obtain data that might be compared with previous investigations of both marine (Pütter, 1924, Waksman and Carey, 1935a) and non-marine organisms (Callow, 1924; Cook and Stevenson, 1928; Harvey, 1928; Martin, 1932; etc.), the amount of nitrogen and in most cases the number of cells[4] in the different suspensions were determined. Since the nitrogen content of the dry weight of many bacterial organisms has been found to be approximately 10 per cent (Nicolle and Alilaire, 1909; Hopkins and Peterson, 1929; Hirsch, 1934), one can (by assuming that this value holds approximately for the species in the present study also) readily arrive at a rough figure for oxygen consumption in terms of dry weight of the cells. Dry weight could not be determined in the present study because most of the organisms cytolyzed readily in distilled water, making adequate washing of the cells for weighing purposes almost impossible.

For each species of bacteria, several Petri plates containing sea-water agar (Waksman, *et al.*, 1933) were heavily inoculated and incubated 24 hours at room temperature. The growth was removed from the surface of the agar by gently brushing it into some sterile sea water with the aid of a camel's hair brush. The cells were centrifuged and washed twice with sterile sea water, and finally suspended in sterile M/4 phosphate buffer,[5] at pH 8. The buffered suspension of cells was aerated with a stream of filtered air for ten to fifteen minutes. Two cubic centimeters of the suspension were then transferred to the usual conical-shaped Warburg respirometer vessels in duplicate, each vessel containing 0.2 cc. of 10 per cent KOH solution in the inset, and the oxygen consumption followed manometrically over a period of from two to four hours. The gas phase in the vessels was air, and the speed and amplitude of shaking were, according to earlier experiments with suspensions of various densities of cells and rates of oxygen consumption, more than sufficient to insure full respiration and complete absorption of CO_2. As soon as possible after placing the manometers on the thermostat, the number of cells per cubic centimeter in the respective suspensions was determined by direct microscopic count of a standard calibrated loopful of suspension spread over an area of 4 sq. cm. on a microscope slide and stained with methylene blue. The number of cells was usually near 10^9 per 1 cc. Macro-Kjehldahl determinations of the nitrogen in 50 cc. (or more) of the same suspensions gave, on the average, a value of about 0.06 mgm. nitrogen per 1 cc. of suspension

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[4] All the counts, and most of the preparations for the counts, were made by Dr. Margaret Hotchkiss. The writer is also indebted to Mr. Theone Cordon for assistance in the nitrogen determinations.

[5] Sea water itself was not used as the suspension medium in order to avoid the initial rise in pH resulting from the absorption of CO_2 in the respirometer vessels. Preliminary work on one of the organisms indicated no significant difference in the rate of endogenous O_2-uptake of the cells in phosphate buffer, M/2 NaCl-dilute borate buffer, or sea water-dilute borate buffer. Strong borate (M/4) buffer alone abolished O_2 consumption. The oxidation of glucose went on at a much greater rate in phosphate buffer than in either of the other two suspension media tried.

The glucose and alginic acid solutions were made up to 0.2 per cent, sterilized by filtration through a Seitz filter, and stored in sterile containers. One milligram (0.5 cc. solution) of the alginic acid was added to the cells from the side arm of the respirometer vessels, after the rate of oxygen uptake without added substrate had been determined. The glucose was added to duplicate vessels at the start of the experiment, and direct comparison made with the rate of oxygen uptake in check vessels containing corresponding amounts of the same suspension of bacteria, but without the substrate.

In the experiments carried out at lower temperatures, the thermostat was controlled by means of a cooling coil of an electric refrigerating unit,[6] whose relay was connected by a vacuum tube relay with a mercurial thermoregulator in the water bath.

The ratio of oxygen uptake to nitrogen content in milligrams, for 25 species of bacteria at 25°C. over a period of two hours, is shown in figure 1. During this period, the decrease in the rate of respiration with time appears to be in most cases slight. The same results calculated in terms of oxygen consumed per 10^9 bacterial cells are illustrated in figure 2. As one would expect, both methods of calculation show considerable differences among the different species in the rates of their endogenous O_2 uptake. The distribution is somewhat more uniform in terms of O_2/N than in terms of O_2/cells, since a larger number of species have a rather slow rate of oxygen consumption expressed in terms of oxygen uptake per cell. It seems evident, from the data at hand, that there is no direct relation between the nitrogen content of the cells of different species and their rates of respiration.

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[6] The writer is indebted to Dr. A. C. Redfield and Mr. Ketchum for the loan of this apparatus, and for the assistance of the latter in assembling it.

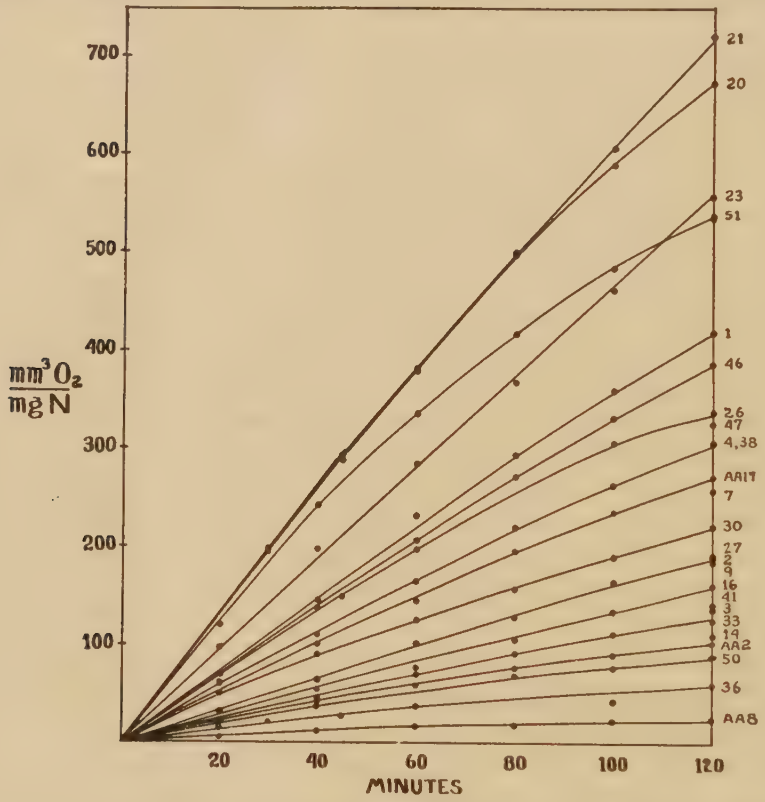

Fig. 1. Rates of Oxygen Consumption, in Terms of O_2 per Milligram Nitrogen, by Washed Cells of 25 Species of Marine Bacteria

A question naturally arises concerning the accuracy with which the number of cells was determined. The results of both the plate counts of viable cells and the direct counts of total cells, just before and following a four-hour period in the respirometers, are reported in table 1. The plate counts are in fairly good agreement, indicating a slight increase (except for species 1) in the number of cells where glucose was added and a slight decrease without glucose. The direct counts show greater variability.

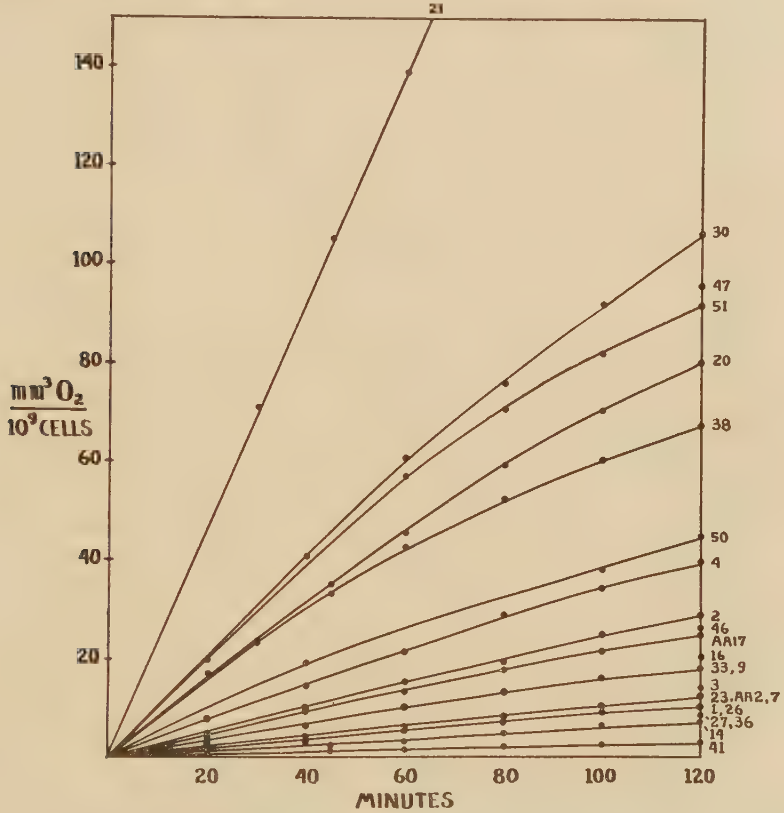

FIG. 2. RATES OF OXYGEN CONSUMPTION, EXPRESSED IN TERMS OF O_2 PER CELL, BY 24 SPECIES OF MARINE BACTERIA

A comparison of the rates of endogenous oxygen uptake by two bacteria, at 5°, 15° and 25°C., is given in figure 3, A and B. Successive experiments, using the same species, were plotted, to show the degree of variation at the different temperatures. Out of a total of 16 experiments, the extreme variation in oxygen uptake per milligram nitrogen amounted to 88 per cent, which apparently

TABLE 1

Comparison of plate counts and direct counts of the cells in three suspensions previous to and following a period of four hours in Warburg respirometer vessels

SUSPENSION OF SPECIES NUMBER	PLATE COUNT: CELLS × 10⁹/CC.			DIRECT COUNT: CELLS × 10⁹/CC.		
	Before	After 4 hours		Before	After 4 hours	
		No glucose	+ 1 mgm. glucose		No glucose	+ 1 mgm. glucose
AA17	0.65	0.60	0.75	1.05	0.55	0.60
1	1.35	1.20	0.85	0.65	0.70	0.30
21	1.05	1.00	1.30	1.25	0.62	0.40

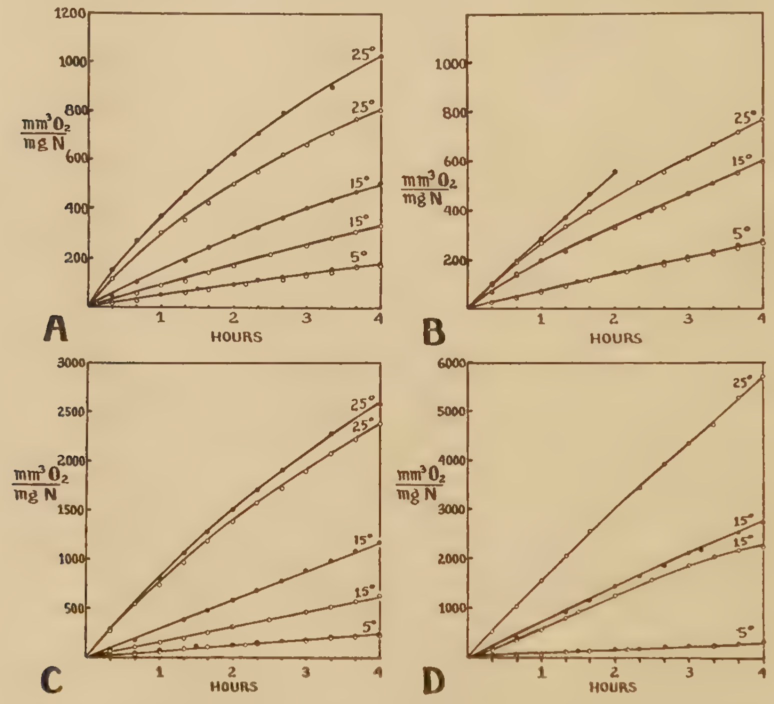

FIG. 3. OXYGEN CONSUMPTION OF WASHED CELLS OF 2 SPECIES OF MARINE BACTERIA, IN TERMS OF O_2 PER MILLIGRAM N, WITH AND WITHOUT ADDED GLUCOSE, AT DIFFERENT TEMPERATURES

A and B, without glucose; C and D, with glucose. Solid and hollow circles represent values obtained in repeated experiments.

is not excessive for bacteria. Callow (1924), for example, found that the variation may amount to as much as 250 per cent, in terms of O_2/milligrams dry weight. In the present study, the extreme variation did not exceed 200 per cent in terms of O_2/number of cells. The rate of oxygen consumption in the presence of 1 mgm. glucose is illustrated in C and D, figure 3. These may be compared directly with A and B, for they were made on the same suspensions of bacteria. It was found that, as was the case with luminous bacteria (Johnson, 1935), the increase in oxygen consumption due to addition of glucose varied considerably in successive experiments, as well as with different species of organisms. The oxygen consumption of all the bacteria studied, using glucose and sodium alginate as substrates, is summarized in table 2. Only those organisms which gave an increase of more than 5 per cent oxygen uptake over a period of two hours, in the presence of alginic acid, were listed. The great abundance of marine bacteria capable of oxidizing alginate (Waksman, Carey and Allen, 1934) is very obvious. The temperature coefficients

TABLE 2

Oxygen consumption of washed cells of marine bacteria with and without added glucose or alginic acid

SPECIES NUMBER	CUBIC MILLIMETERS O_2 PER MILLIGRAM N PER 2 HOURS											
	5°C.			15°C.			25°C.					
	Endogenous	With 1 mgm. glucose	Increase	Endogenous	With 1 mgm. glucose	Increase	Endogenous	With 1 mgm. glucose	Increase	Endogenous	With 1 mgm. alginic acid	Increase
			per cent			*per cent*			*per cent*			*per cent*
23	142	156	10	331	1,417	328	503	3,631	621	557	847	52
21	149	167	12	382	561	46	659	1,546	134	721	778	7.9
AA17	92	126	36	232	446	92	464	1,156	149	271	333	22
1	82	397	378	143	1,141	691	421	2,022	380			
2	39	131	235	164	1,221	644	243	2,864	1,078	190	321	68
4	54	129	138	84	492	485	314	1,830	482	306	350	14
7	85	274	222	164	1,212	639	334	2,637	689	258	405	56
14	89	231	159							112	126	12
41				52	1,733	3,232	74	1,546	1,989	141	182	29
33										136	148	8.8
AA2										104	219	110
AA8										26	31	19
Average..	91	201	148	194	1,028	769	378	2,154	690	256	340	36.2

for the endogenous uptake as well as for the oxidation of the glucose are reported in table 3. The unusually high Q_{10} of 9.1, between 5° and 15°C., for the oxidation of glucose by species number 23, seems to suggest the possibility that, for some bacteria, there may be a critical temperature between 5 and 15°, below which glucose is oxidized only very slowly.

The amount of dissolved organic matter in sea water is small, amounting to only around 2.3 grams of carbon in 1 cubic meter (Krogh, 1934), equivalent to 0.00023 per cent carbon, as compared with 0.016 per cent carbon in most of the experiments in the present study. Since glucose appears to be the most readily utilizable sugar (Kendall and Gross, 1930), it would hardly seem likely that the rate of endogenous oxygen uptake by bacteria in sea water would be increased to any considerable extent by the dissolved organic matter, above the values given in table 2 for the respective species. During active bacterial reproduction, the rates of oxygen consumption might be expected to be higher than during the "resting" periods. In this connection, it is interesting to compare these results with the data of Waksman and Carey (1935b, table VI), on the rate of oxygen consumption and bacterial multiplication in stored sea water. They found that at 22°C., the addition of 10 mgm. glucose per liter (0.001 per cent) caused an increase in total oxygen consumed over a period of two

TABLE 3

Temperature coefficients for oxygen consumption per milligram N per two hours of 8 species with and without added glucose

SPECIES NUMBER	Q_{10} (ENDOGENOUS)		Q_{10} (+ 1 MGM. GLUCOSE)	
	5° to 15°C.	15° to 25°C.	5° to 15°C.	15° to 25°C.
AA17*	2.5	2.0	3.5	2.5
21*	2.5	1.7	3.3	2.1
23*	2.3	1.5	9.1	2.5
1	1.7	2.9	2.8	1.7
2	4.2	1.4	1.1	2.3
4	1.5	3.7	3.8	3.7
7	1.9	2.0	3.2	2.1
Average......	2.3	2.18	3.8	2.4

* Average values obtained from 2 or 3 repeated experiments.

days (between the first and third) of 197 per cent. The average per cent increase in O_2 uptake by the "resting" cells of the 8 species studied here, at 25°C., was found to be 690 per cent. However, the concentration of glucose was 40 times that used by Waksman and the per cent increase was found to be considerably less at lower concentrations of glucose. Waksman's data show that, between the first and third day, when the bacterial population remained practically stationary, the oxygen consumption per cell (taking the average number of cells over the two day period) per hour amounted to 16.5×10^{-9} $mm.^3$, without glucose, and to 18.4×10^{-9} in the sample containing an initial concentration of 0.001 per cent glucose. In comparison with these values, the average value for the endogenous oxygen uptake per cell per hour, over a period of two hours, of 24 species taken at random, was 21.3×10^{-9} $mm.^3$, at 25°C.; this is an extraordinarily close agreement, considering that the figures were arrived at by two such widely different methods. Furthermore it is a definite indication that the bacteria alone could easily account for the oxygen consumption in stored sea water, as described by Waksman and Carey (1935a and b).

In the present investigation, no organism was found capable of consuming as much oxygen as 534×10^{-9} $mm.^3$ per cell per hour, as reported by Pütter (1924) for *Bacterium fluorescens-liquefaciens* in sea water. It is necessary, however, in making comparisons with the rates of O_2 uptake for various bacteria reported by different workers to emphasize that they have not all been obtained by the same procedure; it has also been frequently found that organisms of the same species may vary widely at different times in their rates of respiration.

SUMMARY

The rates of oxygen uptake by washed cells of 25 species of bacteria freshly isolated from the sea were found to vary between 2×10^{-9} and 132×10^{-9} $mm.^3$ per cell per hours, with an average for all species of 21.3×10^{-9} $mm.^3$ In terms of milligrams of nitrogen the variation was between 15 and 360 $mm.^3$ O_2 per hour, with an average of 140, for all species.

The increase in the rate of O_2 uptake in a 0.04 per cent glucose solution varied for 8 species between 10 and 378 per cent, with an average of 148 per cent, at 5°C.; between 46 and 3232 per cent, with an average of 769 per cent, at 15°C.; and between 134 and 1989 per cent, with an average of 690 per cent, at 25°C. The average temperature coefficients for the endogenous O_2 uptake of 8 species were Q_{10} 2.3, between 5° and 15°C., and 2.18, between 15° and 25°C. For the oxidation of glucose, the average Q_{10} was 3.8, at 5° to 15°C., and 2.4 at 15° to 25°C.

Sodium alginate, in concentration of 0.04 per cent increased the rate of oxygen consumption by the washed cells of 11 out of the 25 species tested, the per cent increase ranging from 7.9 to 110 per cent, with an average of 36.2 per cent.

The writer acknowledges with pleasure and appreciation the generous interest of Dr. Waksman in this work.

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Contribution No. 96

Investigations of the Herring of Passamaquoddy and Adjacent Regions

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ABSTRACT

The young herring ("sardine") fishery is seen as partly dependent on extremely local conditions. The fish first appear in the catches when about 12 months old in August. They are generally segregated into shoals of similar length (within an age-group). Certain areas tend to have herring of particular sizes. The "sardine" region is poorly supplied with herring fry rather than well supplied. Turbidity of the water is the only physical factor found possibly rendering the region specially attractive to herring. Euphausiids at the surface are one of the striking features of the heart of the "sardine" region. The principal species of plankton animals (*Thysanoessa, Calanus, Sagitta*) behave in a manner best explained by diurnal quiescence and nocturnal activity. Large landings of "sardines" in the "sardine" region as compared with other places is partly to be explained as due to especial ease of capture in that region, but it is uncertain whether there is a larger population of fish. It is clear that the proposed dams across the mouths of Passamaquoddy and Cobscook bays would make considerable havoc of the exceptionally rich fishery in their neighbourhood. The fishery inside the dams would almost certainly be reduced to negligible proportions, since it seems dependent on immigration. It cannot be foretold whether the total effect on capture immediately outside the dams would be deleterious or not. There appears little possibility of a wide-spread effect, for example along the coast of Maine, or even seriously at Grand Manan.

I. NARRATIVE

Under the International Passamaquoddy Fisheries Commission, an investigation was undertaken in connection with the proposal to install power dams across the mouths of Passamaquoddy and Cobscook bays at the international boundary between the province of New Brunswick and the state of Maine. The results obtained for the phytoplankton have already been published (Gran and Braarud 1935). Papers on the hydrography and the zooplankton are to follow.

The fishery side of the investigation was mainly concerned with the herring, the most important commercial species in Charlotte and Washington counties.* The period from September 1931 to November 1932 was spent in the field of observation, with a base at St. Andrews. Inquiries on a preliminary tour of the coast from Portland to Halifax revealed the necessity of observations on the very young herring, at the stage when they are mainly moved with the water currents, and it seemed that these observations should extend as far as possible in the bay of Fundy and to eastward and westward. The correct season was the winter, and for this purpose the motor vessel, the "Nova IV" was used to make 323 hauls of a suitable net from the 11th of December to the 29th of June. The area of observation extended from the head of the bay of Fundy to the vicinity of Boston, to Brown's bank and as far east as Liverpool, Nova Scotia. Similar observations were made from the U.S. vessel "Pelican" towards the end of September 1932 in the mouth of the bay of Fundy.

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*Most of the place names may be found either on figure 5 or on figure 9.

The "Pelican" was used during July 1932 to obtain 47 observations on transparency and surface temperature near the coast of Maine, Fundy and Nova Scotia.

The remainder of the time was occupied in verbal inquiries among fishermen and other people concerned with the fishery, with the examination of material collected at sea and the collection of supplementary material at the coast, and with organisation of collection of special statistics of purchases of sardines by canneries, daily news of the whereabouts of sardines, measurements of length and particulars of weir operation. For these inquiries the motor boat "Prince" was used extensively. A special short cruise was made in connection with an extraordinary fishery that occurred in Maces bay at the time. For this cruise and other work, the Canadian Government vessel "Phalarope" was very kindly loaned.

During the winter of 1932-1933 the information collected was tabulated and arranged, and the published statistics were also studied.

During the greater part of the time in Canada and the United States I had the valuable assistance of Mr. James Bates. Acknowledgement should be made of the assistance not only of my colleagues on the commission staff, but also of Dr. A. G. Huntsman and the staff of the Biological Board of Canada at St. Andrews. In addition special mention must be made of the degree to which Inspectors of the Department of Fisheries have helped me, under instructions kindly given by Dr. W. A. Found. Acknowledgement is also due to the captains and crews of the vessels used, especially Captain Albert Moore of the "Nova IV" and his crew, who cheerfully undertook the arduous duties involved in our winter observations.

In the semi-statistical inquiries we had the valuable co-operation of three canning companies, Connors Bros. of Blacks Harbour, the R. J. Peacock Company of Lubec and the Union Sardine Company of Lubec.

Tables giving details of the sea observations are on file with the Biological Board of Canada.

The following gear was used in making observations and collections.

Petersen net

The Petersen net was made of stramin about 15 threads to the inch (2.5 cm.) and about half of every inch made up of threads (making the lumina about 1/30 inch square (0.72 sq. mm.), *when dry*). It was mounted on an iron ring and towed on two bridles. A weight was suspended from the lowest point of the ring on a strop one fathom (1.8 m.) long.

It was fished for 30 minutes obliquely from bottom to surface, that is, enough wire was let out to allow the net to touch bottom at an angle of 45 degrees; the angle was maintained at 35 to 45 degrees for one third of the 30 minutes, the wire was then shortened to half the previous length and another third of the time fished; the wire was then shortened so as to bring the net within 1-3 fathoms (1.8-5.5 m.) of the surface, and the remainder of the half hour was so fished. According to the depth more or less time was allowed for shortening, which was at the rate of about 12 fathoms (22 m.) of wire per minute.

At thirteen stations the net was fished from surface to bottom, the time, 30 minutes, being divided into 10 intervals, during the first of which the net was fished near the surface, after which enough wire was slacked out to allow it to reach a layer one tenth of the way towards the bottom, and so on.

Metre net (*No. XXOOO-XXO*)

Fished in the same manner as the Petersen, being led from the Petersen wire itself, but held on a piece of rope 39 fathoms (71.5 m.) of which was in the water, or less where the depth of water did not allow the full length. When the Petersen was raised to midwater the townet rope was shortened to half its length. The aim was an oblique haul from 50-0 metres. The duration was necessarily the same as that of the Petersen, 30 minutes.

Metre net (*No. XXOOOO-XXO*)

Fished on a ring that was only 80 cm. in diameter. This was fished obliquely from surface to about two-thirds of the depth for 15 minutes, being gradually slacked away. No closing device was used.

Half metre nets (*No. 15X*)

Fished in the same manner as the metre net (No. XXOOO-XXO).

Bigelow bottle

Used to obtain phytoplankton samples at 1, 10, 25, 40 and 75 metres where the depth allowed. Also used to obtain temperature and sometimes salinity at 25 m.

Iron bucket

Used to obtain surface temperature and sometimes surface salinity. The bucket was soaked over the side for a full minute.

Secci disc

A white enamelled plate 20 cm. in diameter, the reading given being the mean of two, the depth recorded by the metre wheel when the disc became invisible going down, and the reading of the wheel when the disc again became visible on being raised. The disc was watched through a water telescope.

Drift bottles

Drift bottles with four foot (1.2 m.) drags were liberated as follows: July 16, 1932, nos. 455 to 500, at approximately 1 mile (1.6 km.) intervals on a line between 43° 41¾′ N. lat., 64° 40¼′ W. long. and 43° 6½′ N. lat., 64° 6¼′ W. long.; U.S. drift bottles Nos. 4615 to 4621 at 3 mile (4.8 km.) intervals on a line from sta. N241 (42° 38′ lat. 65° 36′ long.) to sta. N242 (42° 59′ lat. 65° 42′ long.); nos. 4622, 4628, 4623-4625 at 4 mile (6.4 km.) intervals from sta. N242 to sta. N243 (43° 16′ lat. 65° 43½′ long.); nos. 4629, 4626, 4627, 4630 to 4634 at sta. N243.

Otter trawl, 15 ft (4.6 m.)

Used at stations 233 and 268. At sta. N233, 10 min. on bottom and 10 min. off bottom.

II. THE SARDINE FISHERY

Dr. Huntsman has repeatedly pointed out that the statistics of landings of herring, including sardine herring, show a marked concentration of landing in Charlotte and Washington counties, which is very clearly seen on the chart prepared by Dr. A. W. H. Needler, reproduced as figure 1 (Huntsman 1928, 1932, 1933, 1934). That chart was prepared for the year 1919 and the statistics for more recent years that are available, 1928-1930, confirm the 1919 picture. The

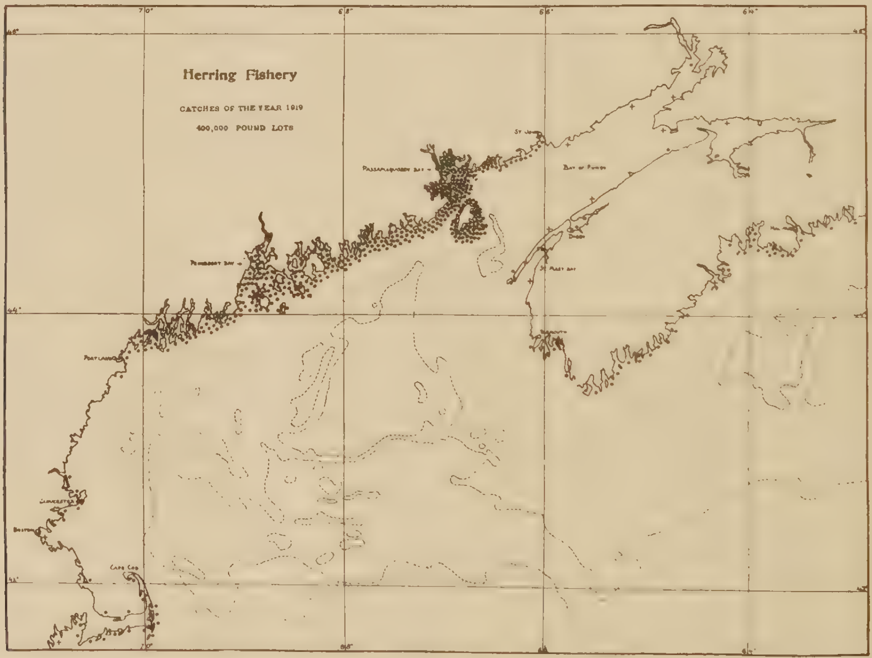

FIGURE 1. Dr. Needler's chart of herring landings. This chart (reproduced by the courtesy of the Biological Board of Canada) was constructed by placing dots opposite each county according to the weight of herring (including sardines) landed in 1919 (information from official U.S. and Canadian statistics). Similar information is given in table II for all years available. The picture for 1919 is found to be valid in the other years examined.

area of this herring fishery may be said to run from cape Spencer to cape Elizabeth, with apparently marked concentration in the Quoddy area. I have attempted some refinement of the same information by dividing the county catches by the length of the coast line, measured on the only chart which takes in the whole area, which, unfortunately, is on the scale of 18 miles (23 km.) to the inch (2.5 cm.). When this is done it does appear that the two areas of greater concentration are about firstly, Washington and Charlotte, and secondly, Knox to Cumberland counties in Maine (table II). It is to be noted that these areas of concentration of landing are each of them west of a great river, namely the Saint John and the Penobscot. This appears to be relevant to an important problem, raised and discussed by Huntsman and Hachey (1934a).

The herring fishery in Charlotte county is of two kinds: the spawning fishery, principally at Grand Manan, and the fishery for immature herring, which are made into sardines. In examining the statistics one may use the figures for sardines alone, or may add them to the figures for herring excluding sardines. In either case one falls into error. Herring of medium size may sometimes be sold to canners and entered as "sardines" and sometimes to smokers and entered as "herring". Other events in the trade may introduce ambiguity, such as canners buying herring larger than they usually like, owing to a scarcity of small fish; or the consignment of large quantities of sardine herring to fertilizer plants. On the other hand, to include the figures for "herring" definitely confuses the spawning fish with the smaller immature fish. On the whole it appears preferable for some purposes to use the statistics for sardines alone, since the errors to which we have called attention are probably without bias and will not usually affect conclusions from averages, whereas the inclusion of mature herring definitely introduces a factor, namely sexual maturity, which we know to be irrelevant, as regards the bulk of the herring which go to make the sardine fishery. From consideration of average figures for such years as we have available (tables III, IV) it is clear that the fishery is in full swing in Charlotte county in May, except for the Grand Manan section, and is still important in October, after which the landings rapidly decline. In Grand Manan and in Saint John county the early part of the season is not so important. In the four divisions of Charlotte county, and in Saint John county, the maximum monthly landing is of the same order of magnitude. We have found by measurements that the coast lines are also of the same order of magnitude (counting Saint John county only as far as cape Spencer because there is little sardine fishery further east), whence it appears that the maximum concentration of landings is not *vastly* different in any part of the New Brunswick side of the mouth of the bay of Fundy. There are, however, differences in the incidence and length of the season and, in our short series of figures, eastern Charlotte seems less productive than the rest. In Charlotte county, excluding Grand Manan, there is some tendency for the May catch to be higher than the June, causing a saddle in the curves of monthly landings. These various details will not now be considered further, since their description really demands a complicated inquiry into the incidence of the variations, and mathematical tests of their significance, work which is not justified from the point of view of the present investigation.

In Charlotte county all the herring are taken in weirs (figure 2 is a photograph of weirs). All weirs are not equally good, in fact it would almost appear that every weir has its own peculiarities. Successful and unsuccessful weirs may be closely adjacent. For example, in a place we may call locality A an inspector described two weirs as among the least successful in his district. They are ⅓ mile (0.5 km.) apart. A circle with ½ mile (0.8 km.) radius drawn round a point half way between them encloses 7 other weirs of which no less than 5 were described by the same inspector as among the most successful. In another place, an open bay B, there are 4 weirs within one mile (1.6 km.). Three were placed in the highly successful category, but the fourth was selected as among the markedly poor ones of the district. Peculiarity of weir-fishing is also seen in seasonal records. For example, the Frye's Island Corporation, whose records were made available to me by the courtesy of Messrs. Connors Bros., operate ten weirs on Frye's Island (Chart names "Cailiff island" and "Payne Island", "Cailiff" being a misspelling, according to Miss Helen Mowat of St. Andrews, who is a descendant of the original Calef). The averages of five years' records of

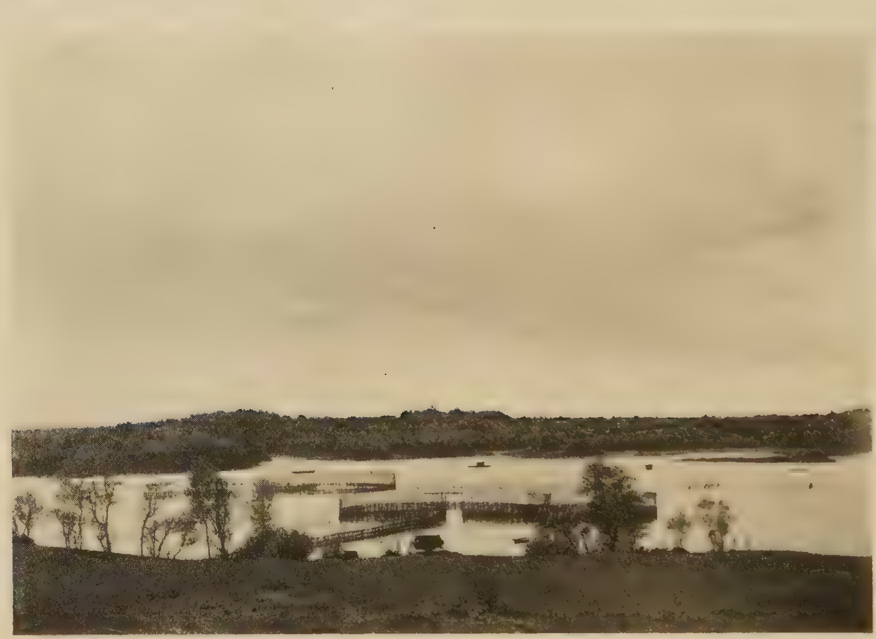

FIGURE 2. Weirs in Harbour de Loutre. Two weirs (central and left) are ready for fishing. Old stakes of a discarded weir are on the right. There is a dummy on the left hand weir to scare cormorants, which are liable to get into the weir and drive the fish out. The object in front of the central weir is a reel mounted on a float. On the reel is wound the purse seine used for taking the fish from the weir. At the right of the weir is the pound, a separate compartment used for retaining herring that are gorged with food, while they digest it; otherwise, presumably owing to autolysis and decay of semi-digested food, the fish will not go through the canning process. The lower part of the weir is of wood and brushwood, and netting, so called "twine", is hung in the upper part.

monthly sales of these weirs are given in table V and shown graphically in figure 3. Positions of the weirs are shown in the chart of figure 4. Eight of the ten weirs show a peak in May (exceptionally April), but this spring fishery is notably absent or poor in "Calef Beach" and "Tarpot". The "Cumberland Shore" weir is consistently the best yielding weir of the ten, but in August and September the monthly sales from "Calef Beach" are of the same order of magnitude as the "Cumberland Shore". No explanation is now tendered of these phenomena, but the facts are given to emphasize the consideration that *this fishery is evidently influenced by factors of which we are profoundly ignorant.* In figure 4 charts are shown, extracted from a collection made of the approximately weekly sales of the same weirs. The whole collection contains many interesting periods, but the one chosen as an example is simpler to describe than

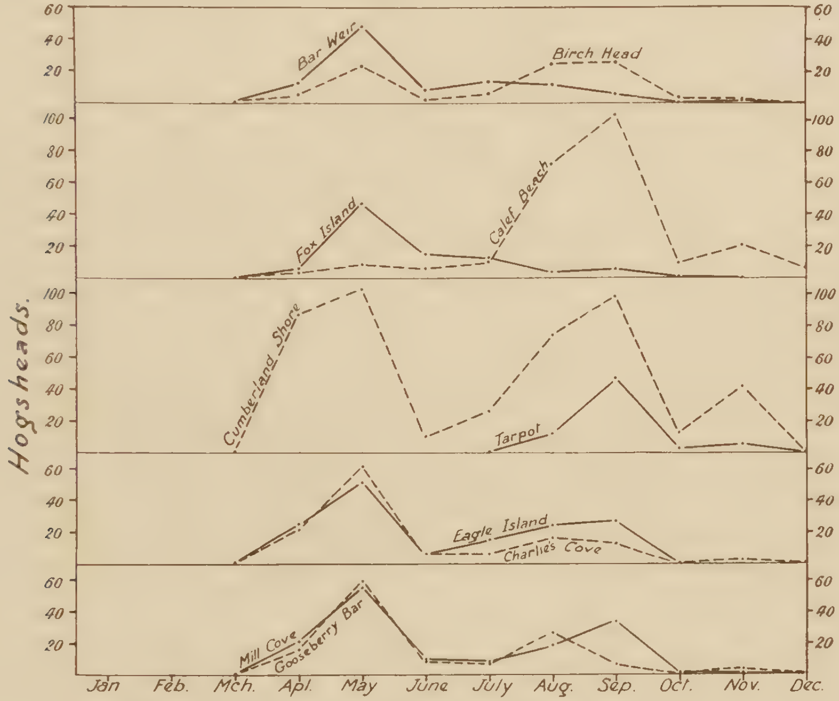

Figure 3. Average fishing of Frye's island weirs. The figure shows the average monthly catch for a period of five years (data in table V). The graphs show individual peculiarities, discussed in the text, p. 101.

the others. It is to be observed that at first none of the weirs were fishing, with the exception of a small quantity sold from "Fox Island" (D). Between May 11 and May 14, however, all the weirs from "Cumberland Shore" (G) to the westward took good quantities of herring. Between May 14 and 21 the same distribution of sales is observed, and this persisted up till May 26, with the addition of a small quantity from "Fox Island" (D). Attention is called to two features. In the first place, despite the strong tides of the neighbourhood,

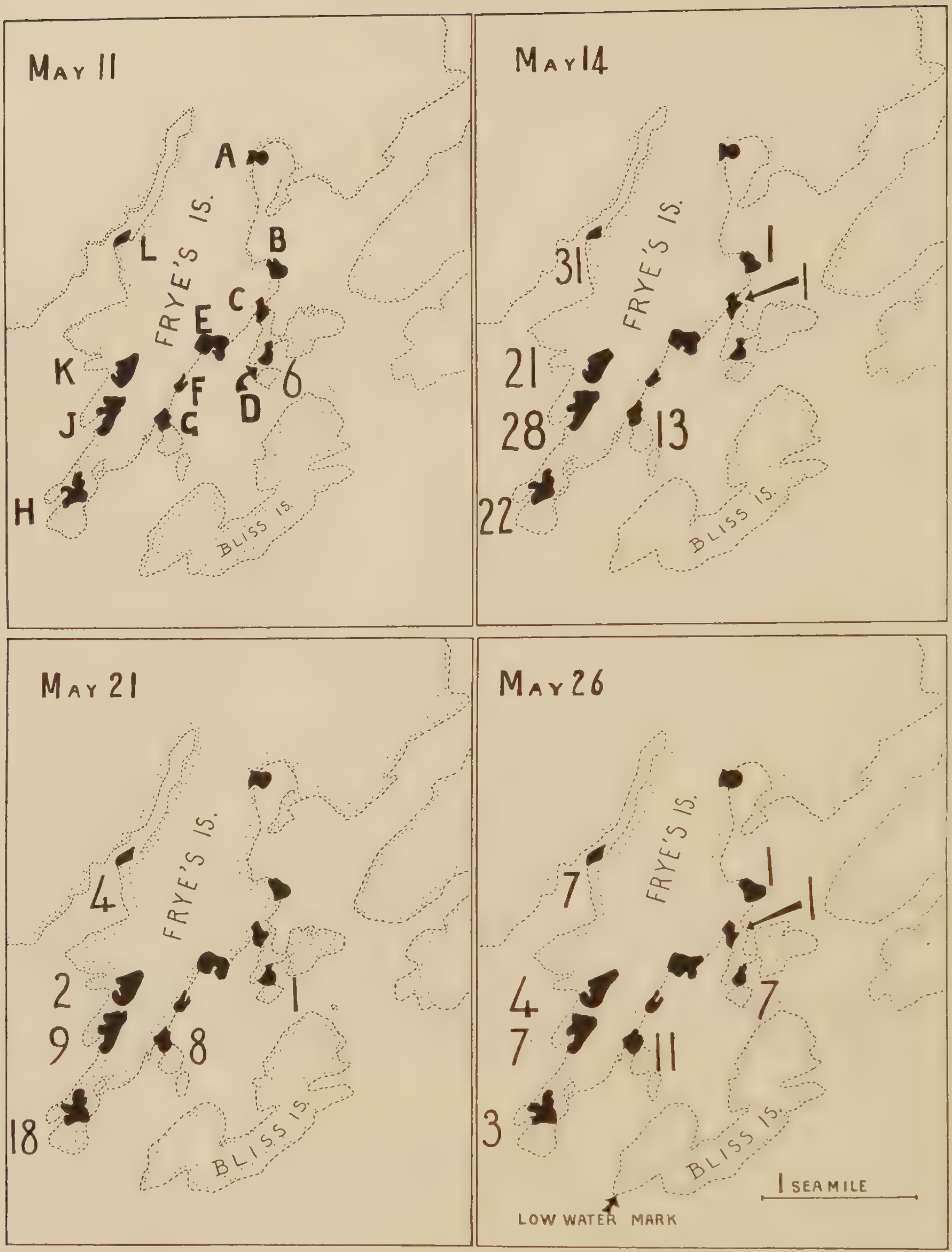

FIGURE 4. Four weeks' fishing of Frye's Island weirs. The four charts are extracted from a collection extending over two seasons. The areas enclosed by the weirs are blacked in and low water mark is shown as a broken line. The numbers give the number of hogsheads sold from each weir. It is to be observed that at first most of the weirs were not fishing, but between May 11 and 14 all the western weirs and the "Cumberland Shore" fished, and that this condition persisted more or less until the week ending May 26, showing some stability of the sardine herring. Two weirs "Calef Beach" and "Tarpot" did not fish, which is usual, these two being good fall weirs, rarely fishing in spring. (Table V and text, p. 101). A "Connors' Beach". B "Birch Head". C. "Bar". D "Fox Island". E "Calef Beach". F "Tarpot". G "Cumberland Shore". H "Eagle Island". J "Charlie's Cove". K "Mill Cove". L "Gooseberry Bar".

there is apparently stability of the sardine herring in relation to the islands. In the second place, the complete failure of "Tarpot" (F) and "Calef Beach" (E) to participate in this fishery is truly remarkable, in view of the fact that they are both within a mile of the productive "Cumberland Shore" (G). We have already seen that this is typical for the spring of the year.

It is abundantly clear that *extremely local conditions influence the catches of herring*, which constitute the total landings. In Passamaquoddy bay the weirs have been closely studied by Huntsman (1934) from the point of view of local conditions. His account is commended to the reader interested in the subject. The present, somewhat bald, account of the fishing at Frye's Island is a less important contribution to the study.

III. MEASUREMENTS OF LENGTH OF SARDINE HERRING

It was thought that light might be thrown on the question of whether the sardine herring of the Quoddy region are to be considered as local, as distinct from being a part of a wide-spread population, by tracing the distribution of herring of characteristic lengths within the area. The same investigation was expected to throw light on the first appearance of young herring in the fishery.

For this purpose two observers measured the length of all the herring in a sample of every consignment reaching two sardine canneries. Altogether the observers measured more than 44,000 specimens in 347 samples. Messrs. Connors Bros. of Blacks Harbour, New Brunswick, the R. J. Peacock Canning Co. of Lubec, Maine, and the E. A. Holmes Packing Co. of Eastport, Maine, kindly allowed this work to be done on their premises.

In default of submitting the entire data, which are cumbersome, an extract is given for the week ending September 17. Table VI gives the statistical area to which the sample was allocated, the length-frequency distribution and the "peaks" determined by inspection. The statistical areas are defined in a table on file and shown in figure 5. There are 50, and the boundaries were drawn as naturally as could be devised. Our data also include the names of the fishermen, but these are now withheld, following a well-established practice. Without the fishermen's names allocation could not have been so precise as it has been. In the majority of cases allocation has been possible to the actual weirs, of which the positions were recorded on a chart. In a proportion of cases allocation had to be to two or more of the numbered statistical areas and, in a few, allocation proved impossible ("N.D." in table VI).

The length frequency distributions were treated by the method of determining approximate modes (and sub-modes) here called "peaks". The word "peak" refers to the shape of the corresponding frequency curve. The chief disadvantage of the method of "peaks" is that the results are not susceptible to mathematical tests of significance, but no better method is known of handling large collections of data such as these, for which the method is extremely suitable and of established efficacy (Graham 1934). The observers appear to have done their work carefully and full reliance is placed on it. There were only two occasions where the records show certainly that they both measured samples from the same weir catch. These results were highly satisfactory. In a Pocologan catch the Blacks Harbour observer recorded a sample with a main peak at 18 cm. and a lesser peak at 22 cm., and the Lubec observer's record yielded the same main peak at 18 cm. and a subsidiary peak at 21 cm. In a catch from Fairhaven, Deer Island, samples of both observers showed the same peak, at 19 cm. All these peaks were determined by an assistant who did not know what their significance would be, so that they are without any bias. (0.5 cm. should be added to all figures given. This correction is omitted in the text for the sake of brevity).

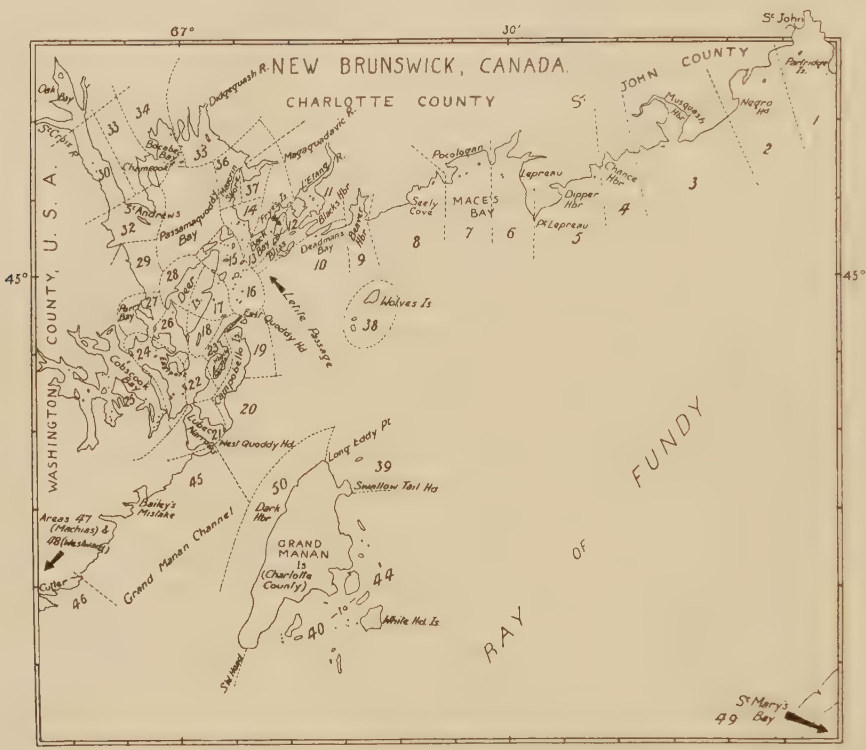

Figure 5. The Quoddy region divided into areas for special statistics. The areas shown here have been used in various tables and in figures 6 and 7.

The peaks were then arranged on 19 weekly charts similar to figure 6. In default of submitting them all, we give table VII, from which all the charts may, if desired, be reconstructed. The charts showed several features of interest which will be described.

First Appearance of Smallest Sardine Herring

The smallest fish to be canned are no doubt first seen in the collection as very highly selected samples from the population, owing to net selection in the instruments of capture. They appeared in the collection first as 10 cm. fish in the week ending September 3 at St. John and Deer island. Connecting these with those recorded in Sections V and VI we are able to call them about twelve months old. Their entry and growth can be followed in table VIII, allowance being made for the masking of growth of the larger by increasing entry of smaller fish. A peak at 13 cm., attributable to this group, was not common until the end of October. Peaks at 11 cm. continue to appear until the end of the season. Mr. T. H. Dorr of the U.S. Fish Hatchery at Boothbay, Maine, kindly looked out for such very small herring. He has sent me measurements of catches made with a drag seine, showing the bulk near 9½ to 10 cm. in September and 10 to 11 cm. in October.

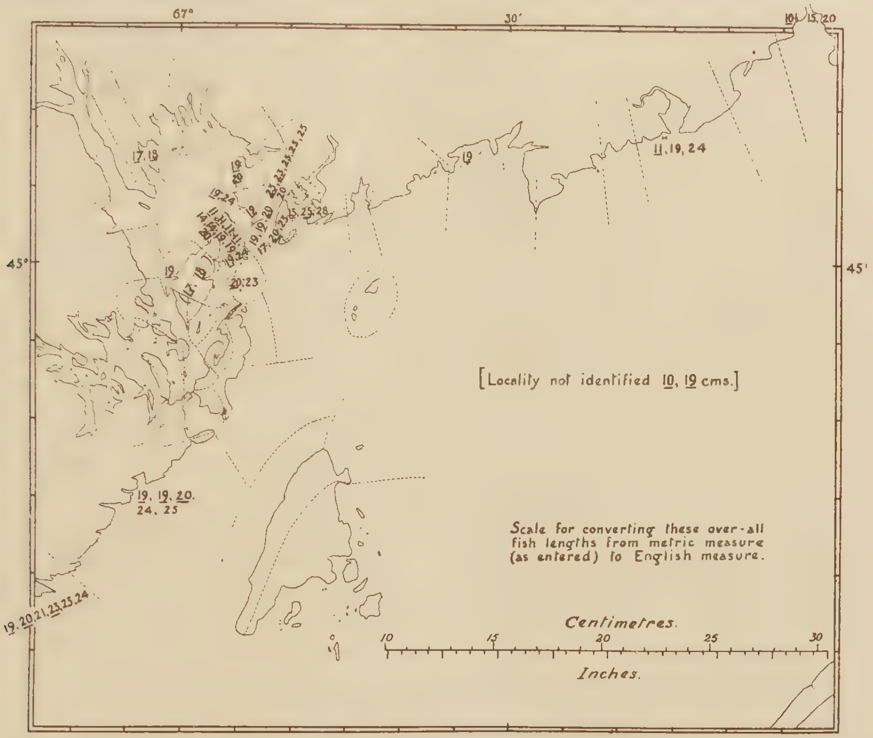
67°
30′
45°
45′
17. 18
19. 24
20:23
15. 25:28
19
11. 19, 24
19. 19. 20.
24. 25
19. 20. 21. 23. 23. 24
[Locality not identified 10, 19 cms.]
Scale for converting these over-all fish lengths from metric measure (as entered) to English measure.
Centimetres.
10
15
20
25
30
Inches.

FIGURE 6. Example of charts showing length of sardine herring. This chart, referring to the week-ending Sept. 17, is one of 19 made for each week of 1932 from August onwards. Data in table VI. The numbers show the commonest length, underlined, and sometimes the next most common length (not underlined) in each sample. These "peak" lengths have been arranged in areas (figure 5). This particular weekly chart is interesting in showing: (*a*) the new entrants, at 11 cm., fish about 12 months old, in three areas, (*b*) the occurrence of particular peaks, *19* amd 24 cm., in widely separated areas, (*c*) the occurrence of a peak at 17 cm. which is rare throughout the collection, in three different areas. Immigration is held to account for (*b*) and (*c*), and these, with similar observations included in table VII, suggest an extensive body of herring in the more open sea, touching the coast here and there.

DIFFERENTIAL SIZE-DISTRIBUTION

There is manifest a distinct tendency for larger sardine herring to be taken in areas 22 and 23 (Friar Roads and Harbour de Loutre) than elsewhere, although big herrings were by no means confined to those areas (*e.g.*, in week ending

September 10, area 13, Back bay, provided many). Conversely the smallest herring were rarely taken in areas 22 and 23. Otherwise they were liable to occur anywhere, but most commonly in area 15 (eastern Deer island). Generally, however, size was not clearly found to be differentially distributed.

SHOALS OF ONE LENGTH

It is very clear that these sardines are taken in shoals roughly of the same length, and peaks are too close to represent different year groups. Pocologan, for example, area 7, yielded main peaks at 18 or 19 (9 samples) and 21 (one sample) in the week ending September 3; Harbour de Loutre, area 23, had 5 samples with main peak 20 or 21, one 22½ and one 25 in week ending October 1; and many other examples can be found.

INVASION OF AREA FROM ELSEWHERE

The frequent occurrence of shoals of the same length in different areas indicate a widely distributed population, or "main body" whose mass movement affects weirs in many places. Thus in the week ending September 17, the combination of peaks at 19 and 24 in one sample occurred in the following areas: Musquash (area 3), Deer Island (areas 15-16), Mascarene or thereabouts (areas 14, 36 or 37), Grand Manan channel (area 45) and Machias (area 46, 19, 23 and 20, 24 cm.). In the preceding week the combination was taken only in area 7, Pocologan, and the peaks occurred separately only in area 5, Dipper harbour (19, 25), area 13, Back bay (20, 24), and area 46, Machias (19), if indeed these can be called the same peaks. There is a strong suggestion here of an invasion of a very extensive shoal striking the coast at a number of points. Another example is samples with peaks at 15 or 17 in September. Fish of 13 to 18 cm. (which I gather were badly wanted by the factories) were comparatively rare (see table VIII). In the fortnight ending August 20 there were 6 samples with peaks 15 to 17, but these fish seem to have grown to 18 to 19 cm. by September 3; for Pocologan, area 7, yielded the following samples:

Week ending:	*Peaks* (*cm.*)
Aug. 13	15, 18.
20	16, 17, 17, 18.
27	18, 21½.
Sept. 3	18, 18, 18, 18, 18½, 18½, 18½, 18½, 19, 21, 21, 22, 23, 23.

In the week ending September 17, however, such desirable herring with the peak at 17 cm., which we can only believe to be fish not previously sampled, occurred in three places, on the 13th in Bliss or Back bay (area 12-13), on the 16th at Chamcook (area 33), and near Deer island (areas 15, 26 or 28). The week previously 17 cm. had occurred, as a secondary peak, in Dipper (area 5), and in the following week it persisted only as a secondary mode at Chamcook (area 33). This suggests immigration and emigration.

Another example, which is not very definite, but is good supporting evidence, is in the week ending August 27, when we had the following similar peaks:

Area 7.	Pocologan		*18*, 21½
Area 40-44.	Grand Manan,	sample (a)	*17*, 19, 21
		sample (b)	22
Area 1.	St. John,	sample (a)	16, 19, *21*
		sample (b)	18½
		sample (c)	18, *22*

Another case of similarity in different areas is:

Week ending September 3:

Area 7.	Pocologan	*18*, *18*, *18*, *18*, *18½*, *18½*, *18½*, *18½*, *19*, *21*, 21, 22, 23, 23.
Area 46.	Machias	*19*, *19*, *19*, *19*, *19*, *19*, 22, 23, 25.

The similarity was continued in the following week.

Another relevant feature is the remarkable rarity of the esteemed and desirable sardine herring of 14 to 17 cm. length. This scarcity was general, which suggests that most of the sardines have been subjected to the same environmental factors, which again suggest an open sea rather than a coastwise habitat.

IV. SPECIAL CANNERY STATISTICS

The official Canadian statistics record the landings of herring and of sardine herrings each year in the Inspectors' divisions of Charlotte and Saint John counties. It was thought, however, that useful information could be gathered if some statistics were arranged in much more detail. Owing to the courtesy of Messrs. Connors Bros. and the R. J. Peacock Canning Co., we were enabled to collect special statistics giving the amount of detail desired. The two firms chosen operated on a large scale and the locations are favourable, one on the eastern side of the Passamaquoddy entrance and the other on the western side.

We include the years 1927, 1929 and 1932. For 1927 and 1929 our statistical unit is one "weekly purchase" of sardines from a fisherman. For example, an entry of "6" might mean that six fishermen sold sardines to the firm in one week or that one fisherman sold sardines to the firm in six different weeks. For 1932 we use a different measure, namely a "daily offer" of sardines, so that an entry of "6" would mean either that six fishermen offered or sold sardines to the firm on one day or that one fisherman offered them to the firm on six days. The statistics have been arranged by weeks and by the areas already described in connection with the length measurement work, Section III. The labour of tabulation, which has been considerable, would have been multiplied many times if we had taken into account quantities of sardines in each offer or purchase. For our purpose it has been sufficient to consider all weekly purchases and daily offers as equivalent to all other weekly purchases and daily offers, respectively. Annual summations of these statistics are shown graphically in figure 7. The outstanding feature of figure 7 is that the coasts on the two sides of Letite passage are the most productive in the region, in all three years. The neighbourhood of St. Andrews and the Bocabec-Digdeguash region appear also to be fairly fruitful in all three years. Differences between years are to be

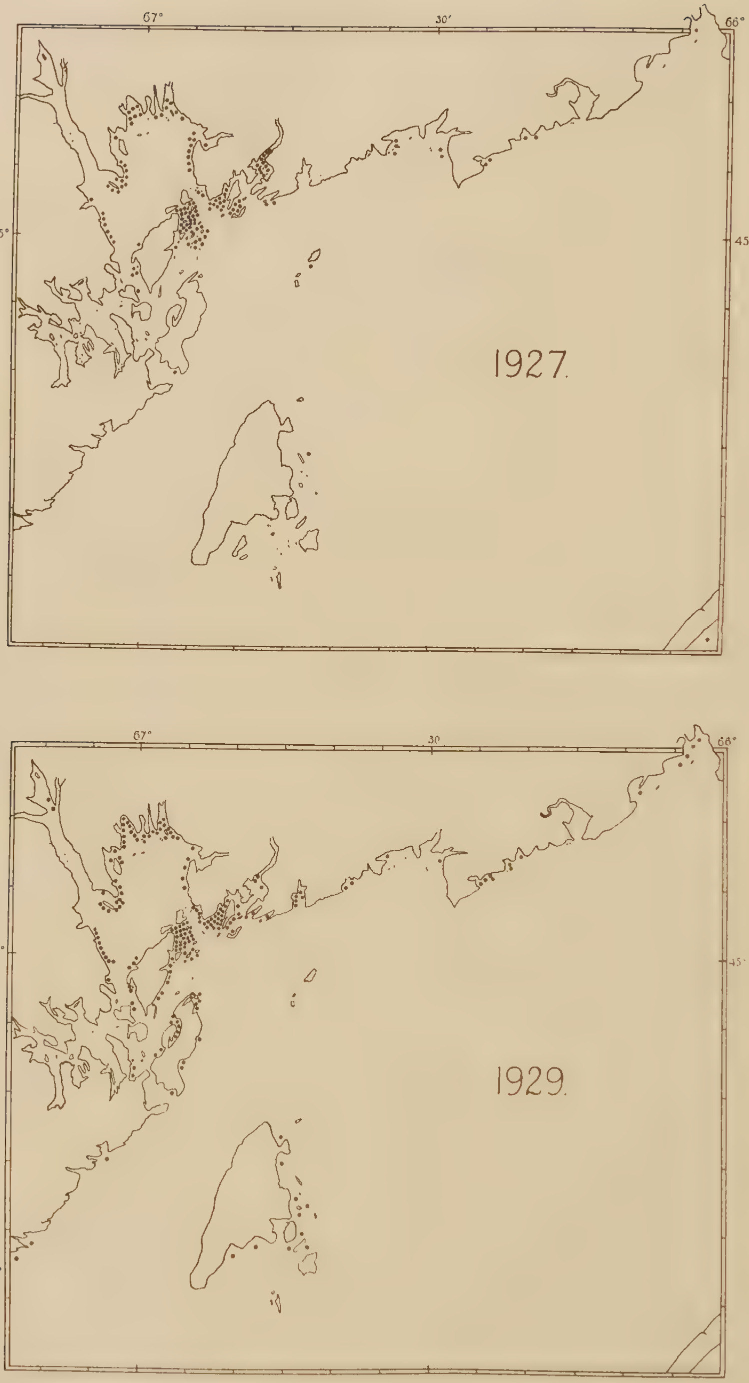

FIGURE 7 (part)

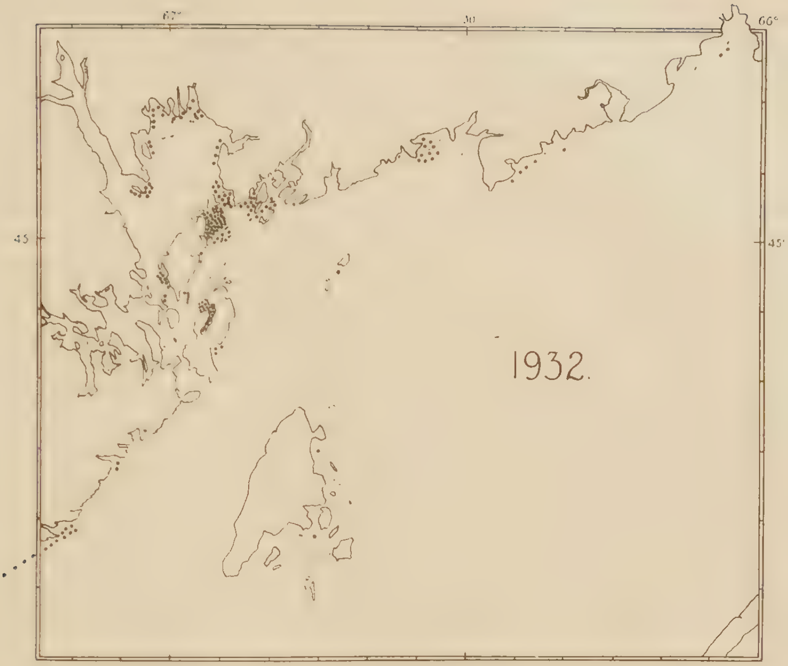

FIGURE 7 (con.). Distribution of sardine purchases or offers. These charts are prepared from information kindly supplied by Messrs. Connors Bros. and the R. J. Peacock Canning Co. Each dot represents so many lots of herring. In 1927 and 1929 (see opposite page), one dot represents 10 "weekly purchases" (equivalent in number to weekly accounts settled) by the two firms (acting separately). In 1932 one dot represents 2 offers of herring to the two firms (again acting separately). In all three years the areas near the Letite passage were clearly the most productive (see also figure 16). The years also show peculiarities, which are discussed in the text, p. 109.

noted in the richness of Pocologan and Harbour de Loutre in 1932, as compared with their comparative poverty in the other two years. Another difference is the remarkable yield from the L'Etang river in 1927, which was not repeated in 1929, nor 1932.

Bias in these statistics is, so far as I could discover, only applicable in two respects. Firstly, Connors Bros. own the company operating most of the weirs on Frye's island which abuts on the eastern side of the rich Letite area, and in 1929 the Sea Coast Canning Co., whose records we are using, acquired weirs in the Machias district, which would bias their purchases in that direction.

The weekly charts of these statistics show many points of general interest, but not sufficiently relevant to warrant their presentation in full. Information from which they can be drawn is on file with the Biological Board of Canada. We have already seen that the length measurements suggest immigration of extensive bodies of young herring (taken in weirs over a wide area) and these data of purchases are not incompatible with the same theory, although they do not show it so clearly. For example, in table IX an extract has been made of the weekly purchases in Passamaquoddy bay areas and Grand Manan areas, and there is sufficient correspondence between the *changes* in the two series of figures to suggest frequent supply from the same source.

The unpublished charts revealed interesting cases of one locality maintaining a supply for a long time, in all three years. In 1927, the L'Etang river supplied sardines from the beginning of July to the end of October, without a single blank week, whereas in 1929 and 1932 this area (11), provided few sardines. In 1929, Dipper harbour (area 5), sold sardines in fifteen weeks out of sixteen between June 15 and October 12, and in eight of those weeks neighbouring areas did not sell to these factories. This phenomenon is ascribed by the fishermen to the herring being penned into bays by their enemies. In 1932 it occurred in Pocologan, where the herring were taken in the middle of July and continued to be taken until the 24th September. Special efforts were made to find whether a remarkable food supply was holding the herring in Maces bay, but plankton hauls taken with the metre net (XXOOOO-XXO) at stations M 1-M 12 revealed nothing abundant, except moderately young eggs of Euphausiids. The fishermen concerned assured us that the herring were not particularly full of food. They were described as "clear of feed". Inquiries by Captain Mitchell of the "Phalarope" in Beaver harbour revealed that the line fishermen of that port had been taking a fair quantity of hake and haddock on the grounds between Beaver harbour and point Lepreau, but that they had had to abandon this fishery owing to an invasion of dogfish in late July. An explanation of the Pocologan herring fishery might, therefore, be that an extensive school of dogfish was holding the herring into Maces bay. The silver hake, *Merlucius*, is more usually credited with the agency for this phenomenon.

Looking over the weekly charts an impression is gained that the first sardines to be taken in the spring are from a not very large population, which has remained during the winter in the region between point Lepreau and Deer island. In 1927 it looks as if this body, whether reinforced or not, entered Passamaquoddy bay only at the beginning of July, whereas in 1929 they were already in the bay in the week ending April 27. The impression is further gained that this winter school is joined by more sardines from the open sea earlier or later in the season, which eventually leave the Quoddy region, so that, at the end, only the passages of Passamaquoddy bay are fishing, just as they were at the beginning of the season. However, no great reliance is to be placed on this impression, which needs substantiation by further research.

V. HERRING FRY INVESTIGATIONS

Figure 8 shows charts of our observations on herring fry (excluding the June cruise, when hardly any were taken). Details are given in tables on file with the Biological Board of Canada.

In September 1932 we took a fair quantity of herring fry from the bay of Fundy, principally on the Nova Scotian side. These were mainly 10 to 11 mm. long; smaller fry were taken southwest of Grand Manan and larger fry near Saint John. None was taken near Petit Manan nor in the vicinity of the Lurcher shoal. It is clear that the fry taken were mainly the product of fairly local spawning in July or August. From the catches of large breeding herring, it is known that there is a considerable spawning ground south west of Grand Manan. By repute, Grand Manan bank is also a spawning ground and there are probably others in places where there is no fishery for the adult herring. The June cruise and the September cruise make it clear that spring spawning produces no considerable contribution to the herring stock, for we took no freshly hatched fry in June, nor any outstandingly large fry in September. This is confirmed in the records of herring fry taken in the zooplankton cruises, of which Dr. Fish has sent me an extract.

Our catches of fry on the Nova Scotian shore in the previous December and January, mainly 22 to 26 mm. long, can be related to the corresponding spawning of the year before. We also sampled in January an extensive body of fry off cape Sable, and similar but even more extensive distribution was found in April. From January to May, the bay of Fundy contained a moderately extensive body of fry on the Nova Scotian side. The Quoddy area and the coast of Maine, notable for the large landings of sardines, were not found to be well supplied with fry at this helpless stage. A remarkable feature of these observations is the general scarcity of herring fry in the bay of Fundy and neighbouring waters. It is true that the method of fishing was probably inadequate from May onwards, (owing to the fry becoming large and therefore active enough to avoid the net), but the fry were found to be scarce in January also. At no time did we find any population of fry commensurate with the enormous numbers of sardines, unless the body taken in April between Seal island and Liverpool is considered sufficiently extensive. The observations, in fact, suggest that neither the Grand Manan spawning ground, nor all the spawning grounds in the bay of Fundy considered together, provide sufficient fry for the population of sardines. If this be true, then the Quoddy-Maine sardine fishery must represent concentration in a small area of the products of very widely distributed spawning grounds.

Growth was apparently very slow from February to April. Within the bay of Fundy the distribution of herring fry would make it appear that there is very little water movement from February to April while the Saint John and other rivers are frozen, and this is supported by the distribution of plankton (Chaetognatha and Ctenophora) (see section VIII), but neither of these lines of evidence can be relied on more than as an indication for further research.

VI. FIRST APPEARANCE OF METAMORPHOSED HERRING

Very small herring, sometimes called "eyeballs", are sometimes seen by fishermen round the coast. It appeared to us from consideration of the work of Mavor (1922, 1923) and of Bigelow (1927), that the currents would set the herring fry, observed in April near Seal island, on to the coast of St. Mary bay in July. With this idea, Mr. James Bates visited Brier island on July 10 where he was fortunate enough to find that the pollack had driven a large quantity of herring of about 5 cm. length on to the beach. At the same time similar herring were taken in the Biological Station's weir at St. Andrews, and report gave them a fairly wide distribution in Passamaquoddy bay. Mr. N. A. McNairn has given

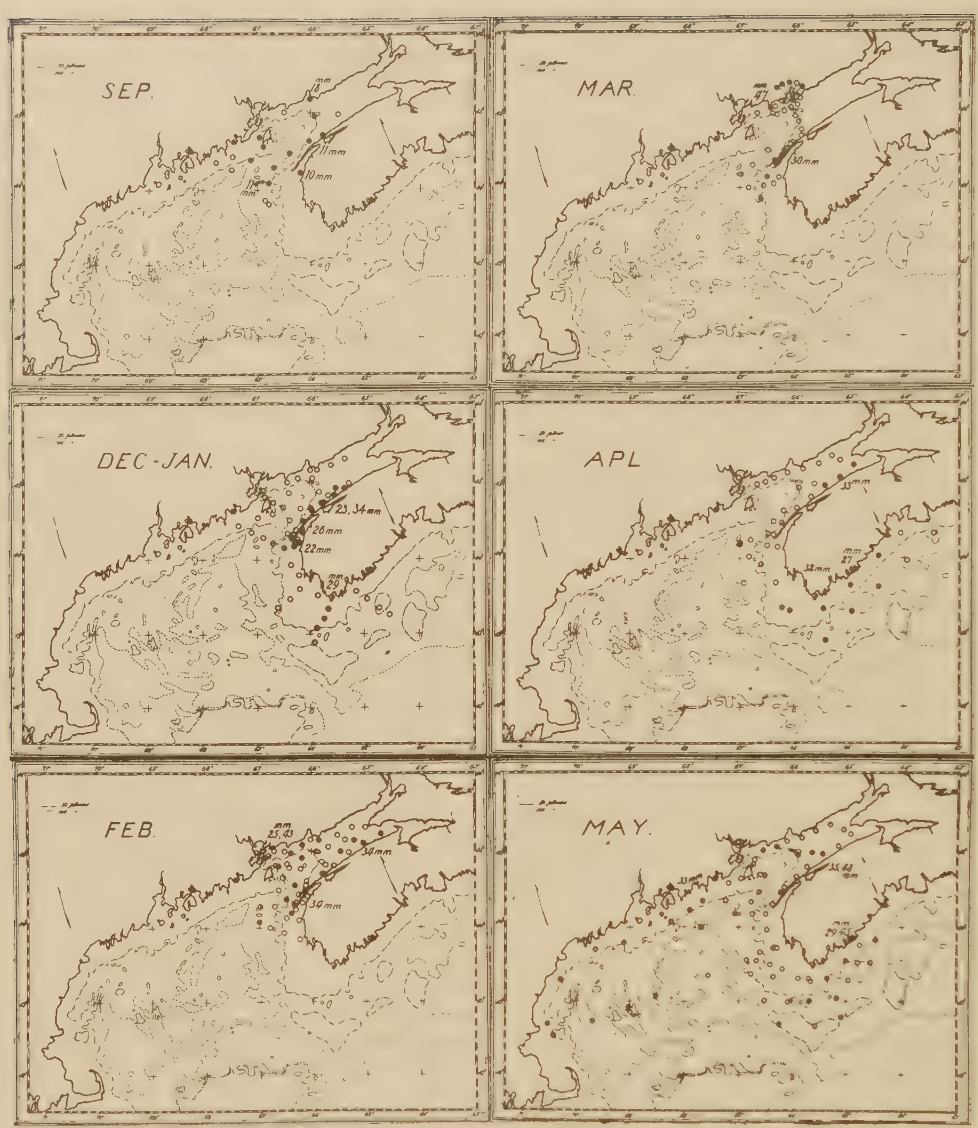

FIGURE 8. Catches of herring fry. In this series of charts positive hauls are shown solid, negative in outline. "Peak" or most common lengths are inscribed near the hauls to which they refer. The numbers per haul were always relatively small (Data on file). It is suggested in the text, p. 111, that the Dec.-Jan. chart shows a distribution derivable from that of the September chart (although the September chart was for the following year), and that the bay of Fundy stock is thus adequately sampled by the observations up to, say, April, showing it as a disperse, and nowhere very numerous, population. Allowing that the fry are more difficult to catch in April and May, owing to their larger size and activity, and that mortality will have thinned them, the stock in April (and May) lying to the south of Nova Scotia is clearly more extensive and abundant.

The sardine area (cf. figure 1) was poorly supplied with herring fry at this (passively drifting) stage.

me an extract of his records of the catches in this weir. These show herring mainly of 6-7 mm. length on July 9 and 13, say 4, 5, 6 and 7 mm. on July 14 and 16, and 8-9 mm. at the end of July and on August 16. The fishermen were unanimous that these would become suitable for canning in about October. We might mention here that in 1931 we saw a barrel of very small sardine herring which had been taken at Shelburne.

The appearance of a later stage, the youngest marketable fish, 10 cm. length in September, has already been noted, section III.

A point of some interest is whether the extensive body of fry that we found in April (figure 8), apparently extending from Seal island round cape Sable to the offing of Liverpool, would tend to be carried to the sardine area. Some limited experiments with drift bottles suggest that they would. Of 50 bottles liberated on a line across La Have bank on July 16, only two (nos. 481, 499) were recovered by March 1933. These two were liberated on La Have bank. One was found at Port Latour on the south shore of Nova Scotia in October, the other near Parkers cove on the Nova Scotian shore of the bay of Fundy in December. Messrs. Herrington and Webster of the U.S. Bureau of Fisheries have kindly supplied particulars of recoveries of bottles liberated between Georges bank and cape Sable. Two liberated near cape Sable in May, Station N 243, were recovered in July and August in the sardine area in the Maces bay neighbourhood. 16 other bottles, liberated in April, 1932, on Browns bank, the neighbouring part of Georges bank and the channel between, were recovered as follows: 1, Newfoundland; 2, outer Nova Scotia; 3, between cape Sable and St. Mary bay; 1, Nova Scotian shore of bay of Fundy; 1, Chignecto side of head of bay of Fundy; 1, Grand Manan; 6, between point Lepreau and West Quoddy head; 1, near Gt. Wass island, which is about midway between Passamaquoddy bay and Mt. Desert island. All but two of the recoveries were made before September 30, 1932.

It seems probable that some, at any rate, of the fry we found in April extending around cape Sable would tend to be drifted into the bay of Fundy, although they might well have passed the "eyeball" stage before reaching the sardine area proper. Of course, should the herring choose to resist the drift, which they would be capable of doing at this stage, this tendency might be nullified.

VII. STUDY OF PHYSICAL CONDITIONS

This branch of the investigation was the concern of my colleagues rather than myself. A special effort was, however, made to compare the coastal waters of Nova Scotia with those of Maine and Fundy in regard to surface temperature and transparency. The observations are given in table I. It was found that in July the most turbid water (between Portland, Maine, and Liverpool, Nova Scotia) was in Passamaquoddy bay and off the Saint John river. The central part of the bay of Fundy, the mouth of St. Mary bay and the water near cape Sable was relatively clear. The whole coastal water between cape Spencer and Seguin, which is approximately the sardine area, was more turbid than anywhere else except the inner part of St. Mary bay and the Annapolis basin, where sardines are also taken. The corresponding surface temperature observations showed the coldest water off cape Sable and the warmest water in St. Mary bay. The water between cape Spencer and Seguin was intermediate in temperature, warmer west of Mount Desert.

Attention should be called to two factors whose distribution is already known. The bay of Fundy is notable for the extreme range of the tides (figure 9). A range of 45 ft. (13.7m.) is recorded in the Minas basin. Going from St. John to Boston there is a gradual reduction in the range recorded, from 22 ft. (6.7 m.) to 10 (3 m.). The range at Digby is 22 ft. (6.7 m.) at Brier island and Yarmouth 14 ft. (4.3 m.), but around cape Sable, we have only 5 ft. (1.5 m.), at Shelburne and 5 ft. at Halifax. The bay of Fundy is also noted for summer fog. If we examine the records of fog at light stations in July, we find indeed, a large area stretching from Cap d'Or to Petit Manan and round Nova Scotia to Halifax where the fog is extreme (figure 9). In July 1930-31 more than 300 hours per month was recorded in the area described. This is the extreme degree of a general condition which stretches as far west as say, Block island, although with marked reductions in western Maine. Winds from SE. to SW. are known to bring fog, and the condition appears to be due to warm, damp air from the Gulf Stream being driven into a region where the surface water is relatively cold. Figures kindly supplied by the courtesy of the two departments of Marine and Fisheries are given in table X.

The residual current picture plotted by Bigelow, 1927, p. 973, as typical for the month of August, shows that usually, the mouth, at any rate, of the bay of Fundy is part of the gulf of Maine circulation, with some contribution from the waters between cape Sable and Browns bank (figure 10). I understand that our own observations with drift bottles and those of the Biological Board of Canada, for which I am indebted to Mr. H. B. Hachey, agree in showing considerable contribution of water from the gulf of Maine to the mouth of the bay of Fundy. This is the summer condition, and we do not know whether it also obtains when the rivers are frozen.

The question of the bay of Fundy receiving contributions from the cape Sable region was specially discussed in section VI.

Important effects of the conditions mentioned in this section are discussed in the paper by my colleagues Dr. Gran and Mr. Braarud (1935).

VIII. PLANKTON. HERRING FOOD

This side of the work was the chief concern of my colleagues, but in the hauls for herring fry we naturally took other forms, constituting a large collection. The customary handling of these in the laboratory could not be undertaken by my colleagues, whose time was more than occupied in dealing with their own collections. Moreover, the comparatively large mesh used for taking herring fry (Petersen net), was highly selective as regards important herring food such as *Calanus*. The collections, have therefore, been handled by a rapid, approximate, but adequate, method of estimation, and the distribution of the commoner groups of animals has been examined. The distribution of ctenophores, figure 11, and *Sagitta*, figure 12, in the bay of Fundy, are interesting, as suggesting almost no water circulation at the time when the herring fry were taken. It is observed that the ctenophores were consistently located principally between cape St. Mary and Digby, and the greater concentration of *Sagitta* was consistently near Digby. Absence of water circulation is the readiest explanation, but it does not follow that this is the true one. The truth may be more complicated, for example, the localities of abundance may be unique in the conditions for survival of the forms, or as points of concentration by mechanical forces, and other explanations may, no doubt, be suggested. The distribution of euphasiids near Saint John in March is shown in figure 13. This is submitted to show the irregularity of euphausiid catches, even with a large net fished from very near the bottom to the surface. The matter is important because these "shrimps" are one of the favourite foods of the sardine herring, and their appear-

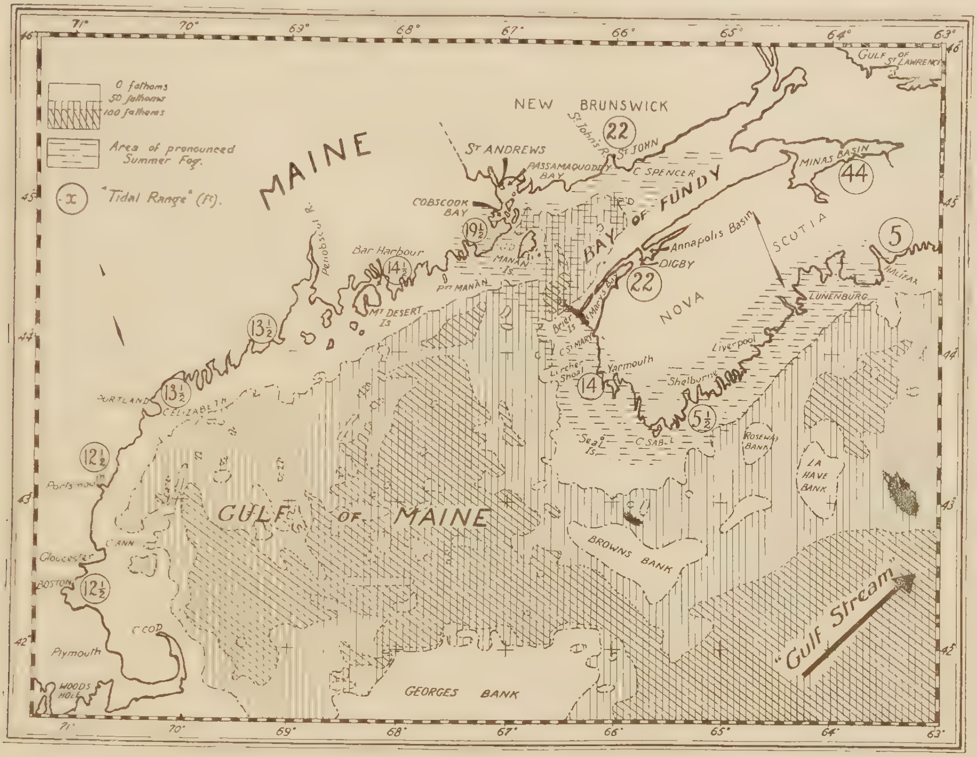

FIGURE 9. Topographical chart of area of investigation. This chart shows depths and place names, also "Tidal Range" and fog. For the Canadian coast the "Tidal Range" is 2 (H. W. Springs level—Mean level) whereas for the U.S. coast we have used a value which comes 2 to 3 feet more namely (H. W. height—Lowest tide). These figures were taken from the respective charts. Fog figures are given in table X. The shaded area includes stations where there was 300 hours or more of fog in July, on the average of years 1930, 1931.

Fog is an indication of cold surface water. The tidal range falls, as one leaves the sardine area, going westward and southward.

ance on the surface is a very frequent phenomenon in the Quoddy area. This appearance on the surface seems to be related to upwelling of deep water, for it is associated with tide streaks. The appearance of the "shrimp", which are easily seen, is generally heralded by concentration and excitement of herring gulls, terns and phalaropes. On occasion, herring may be seen darting about under the places where the shrimp are. Such were the phenomena observed off Welchpool (area 22, figure 5), one day in the summer of 1932. On that day the herring were not observed under the "shrimp" until sunset. The distribution of one of the principal tide streaks, as we normally observed it, and of the gulls as observed one day when a census was taken, are shown in figure 14.

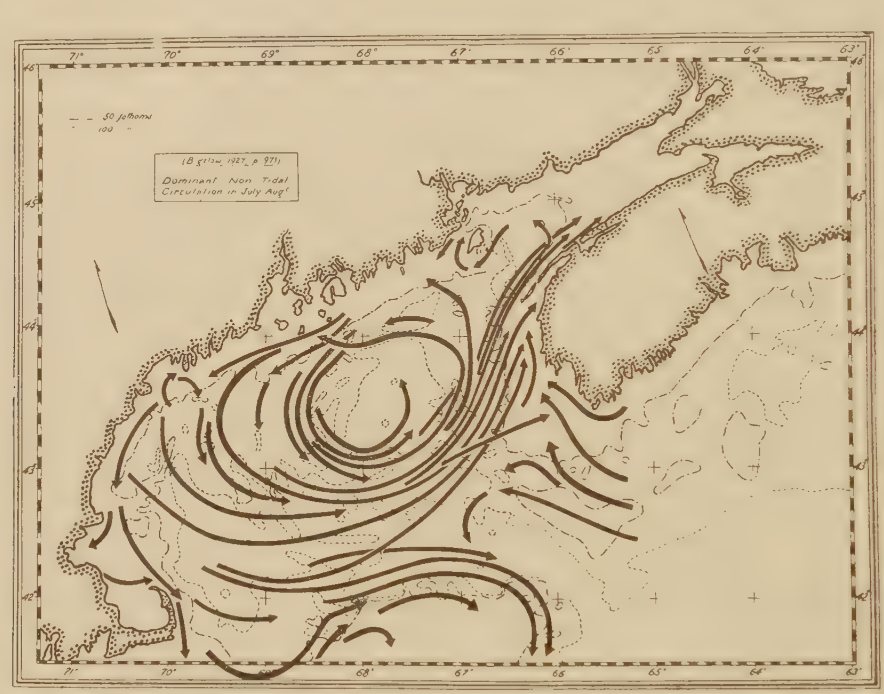

FIGURE 10. August circulation of surface water according to Bigelow. The author of this chart explains that it is made from drift bottle records and is to be regarded only as typical of the circulation shown, not necessarily applying every year.

Figure 15 is a snapshot of about one quarter of one of these gull concentrations. In the short cruise of the "Phalarope" on the 17th and 18th of August 1932, large quantities of euphausiid eggs were taken off Bliss island and in Maces bay, stations M 1 to M 12, with the metre net (XXOOOO-XXO), and local fishermen reported the adults as forming the food of ground fish at that time. It certainly appears that there are large quantities of these "shrimp" in the mouth of the bay of Fundy and elsewhere in the region. (Our records show them commonly off cape Spencer). Undoubtedly euphausiids cannot easily be sampled in a representative manner. A series of 20 hauls were made off Liverpool, Nova Scotia, stations N 217-N 236 with the Petersen net, with the intention of dis-

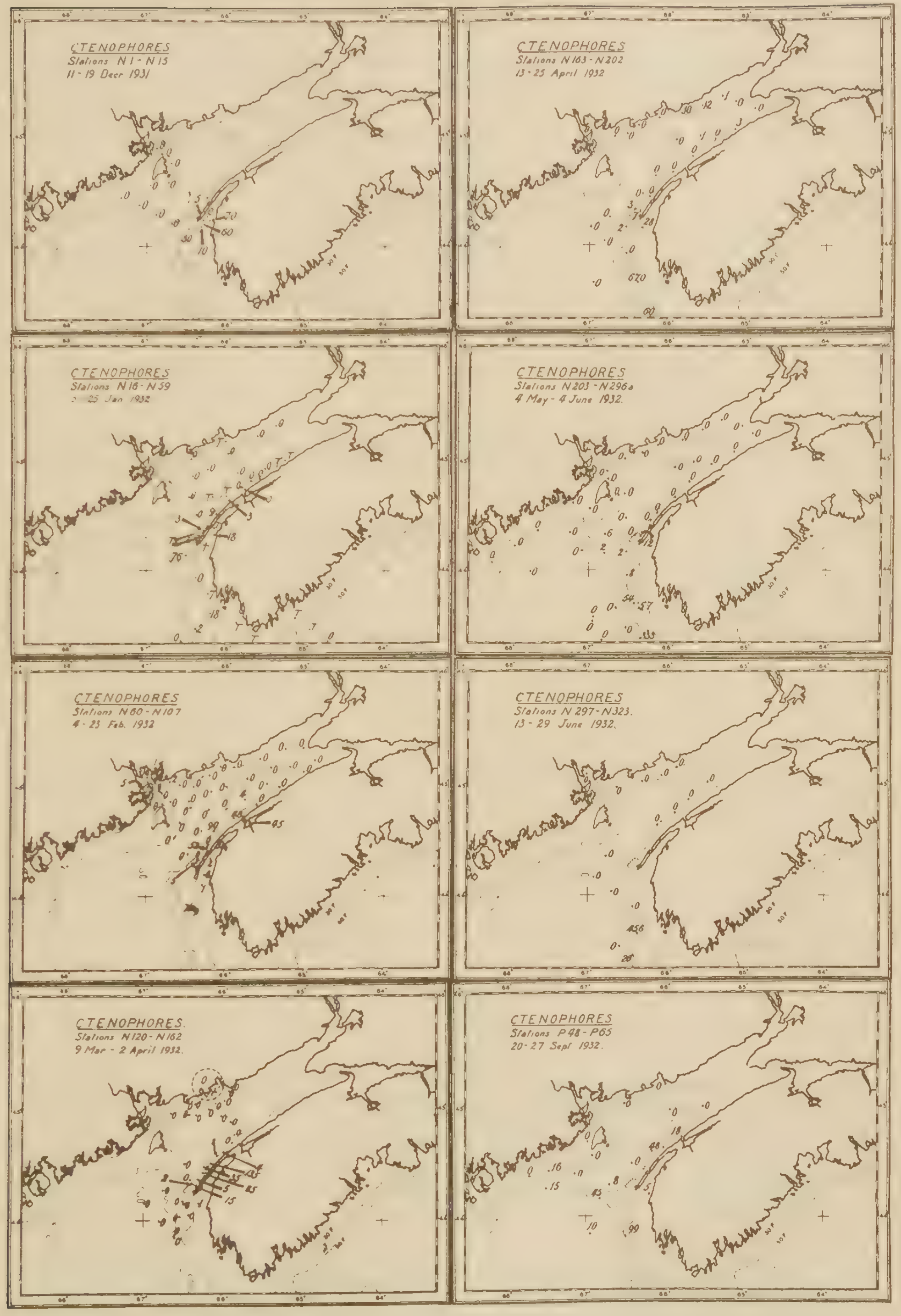

FIGURE 11. Catches of ctenophores. The distribution of these forms is remarkably constant and restricted. They suggest absence of circulation in the bay of Fundy, but can also be interpreted otherwise. The numbers are estimated volumes (in 1/100s of a cylinder, vol. 500 cc.). "T" stands for "trace".

discovering what difference, if any, there was between our day and night catches of herring fry. These hauls did not show any significant difference in the catches of herring fry by day and by night, but it was obvious from the mere appearance of the plankton in the jars that they would give information about the liability of euphausiid and other forms to capture. These hauls, therefore seemed worthy of more exact treatment than we had accorded to the remainder of my collection, and have been examined quantitatively by Mr. A. C. Gardiner, temporarily

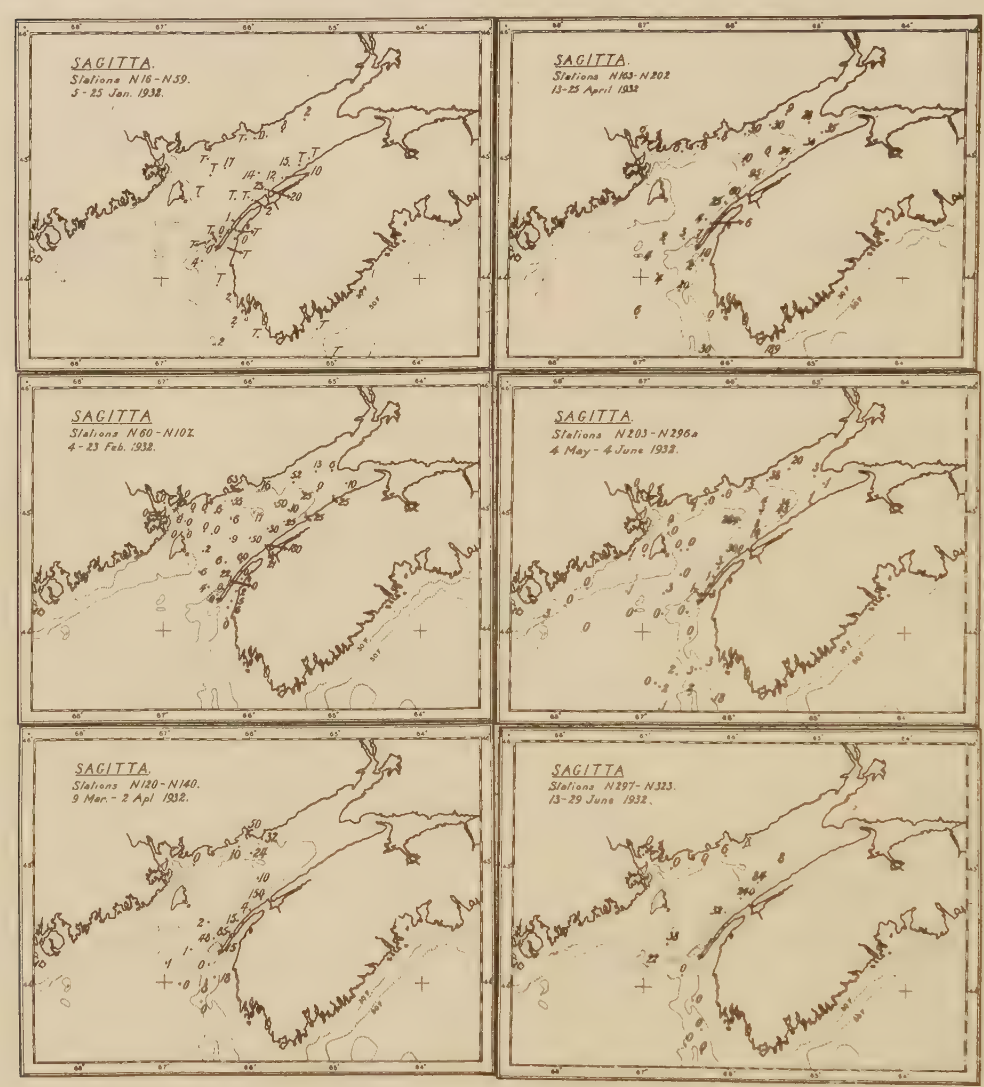

FIGURE 12. Catches of *Sagitta*. The distribution of this form is again remarkably constant (cf. figure 11), suggesting very little circulation in the bay of Fundy, but can also be interpreted otherwise. The numbers are estimated volumes (in 1/100th of a cylinder, vol. 500 cc.).

working at the Fisheries Laboratory, Lowestoft. His report appears to be of considerable interest from the point of view of other food animals, such as the copepods, as well as in regard to the euphausiids. It is as follows:

SUMMARY REPORT ON 48-HOUR PLANKTON COLLECTION

By A. C. Gardiner

The collections, twenty in number, were obtained by oblique hauls, from bottom to surface, of a modified 2 metre ring-trawl (Petersen net).

The twenty hauls were made at approximately 2½ hour intervals and covered a period of 48 consecutive hours; 10 were made during the hours of darkness and 10 in daylight.

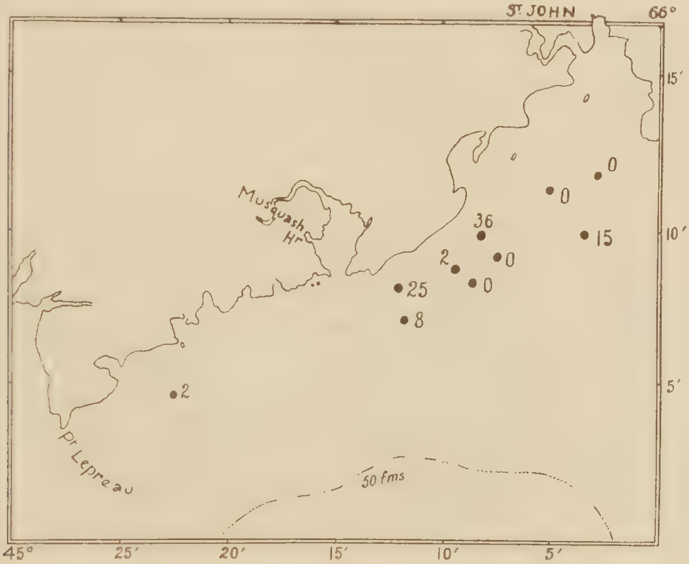

FIGURE 13. Catches of euphausiids near Saint John. This chart is included to show the extreme "spottiness" of catches of euphausiids in hauls close in time and distance (Stas. N 121-125 and N 141-153). Numbers indicate estimated volumes, as in figures 11 and 12.

There were considerable differences between daylight and dark collections. The most striking was in the case of euphausiids (*Thysanoëssa inermis*, *Thysanoëssa raschii* and, very few, *Thysanoëssa longicaudata*), the numbers of which rose to over 5,000 by midnight, whilst in all the daylight collections the animals were virtually absent (0-40 per haul).

As regards the other common species, *Sagitta elegans*, *Calanus finmarchicus* and *Calanus hyperboreus*, it was shown that there was a significant difference between the numbers captured in the daylight and dark collections, the latter being in each case the greater. Adult *C. finmarchicus* tended to disappear to a relatively greater extent than individuals in stage V.

Numerical differences between day and night collections have been noted before but the present data, especially those of euphausiids and *Sagitta*, covering as they do a period of 48 consecutive hours, are particularly interesting.

It is well known that euphausiids, which are believed normally to live in the deeper water by day, may on occasions be found in great abundance right at the surface at midday. This phenomenon was observed during the course of the present experiment, "shrimp" being observed from the deck of the ship in fair numbers round about midday on the second day.

A single specimen captured in a surface bucket was identified as *Th. inermis*. The number of all species of euphausiids taken in the oblique haul at the time nearest to that when "shrimp" were being observed in the surface waters was 29, the maximum number in the preceding period of darkness being 4,179.

Two explanations suggest themselves. Either we believe that these animals being powerful swimmers, can see and avoid a net by day, or we can suggest that normally these animals are nocturnal, a period of inactivity by day following the period of activity during the hours of darkness. When, for some reason, the animals' normal rhythm is upset a number may swim up to the surface in the daylight where the net fails to catch more than a small proportion due either to the animals' own efforts to dodge the net, or to their being on the quite superficial water layers through which an obliquely hauled net would not normally pass.

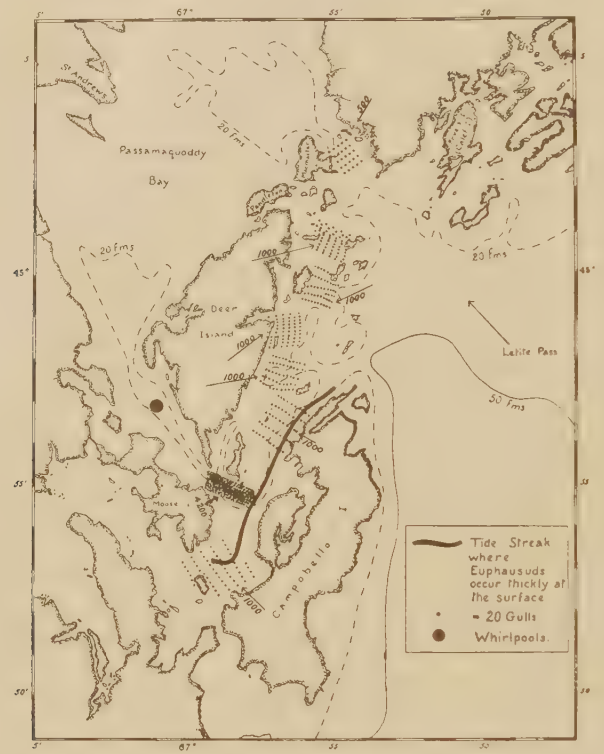

FIGURE 14. Whirlpools, gulls and tide streaks in Passamaquoddy entrances. This chart is largely schematic, for illustration, rather than record. The whirlpools are taken from the admiralty chart. The position of the main tide streak is from memory of several occasions. The gull census is the result of observations on one particular tide, when two patches were photographed and the remainder of the population estimated in terms of these two patches. Subsequently the numbers in the patches were counted on enlargements, and so the whole census evaluated. The total number came to 11,000. We only saw the waters of the main entrance, Friar roads, the way to Letite passage and Letite passage itself, with two traverses of Passamaquoddy bay.

The suggestion will be made that the big differences observed between the numbers of euphausiids, *Sagitta* and *Calanus* spp. by day and night probably lies in the fact that to a greater or less degree these animals are nocturnal. In the day time a proportion (close on 100% in the case of the euphausiid species) sink right to the bottom and are removed from the population sampled by the net. In the case of the other species the proportion which are so removed is smaller.

Neither fish ova or herring larvae show significant differences between daylight and dark collections.

Mr. Gardiner has briefly described these results elsewhere (1934).

The whole collection of plankton (excluding the 48-hour hauls dealt with by Mr. Gardiner) has been stored at the St. Andrews laboratory where, presumably, it is available for any interested persons; and the rough charts of distribution, which we have prepared, have been sent to Dr. C. J. Fish in case they are of interest in connection with his branch of the investigation.

FIGURE 15. Gulls in the Quoddy tide streak. This is a snapshot of about one quarter of a patch of gulls seen off Eastport. (Not on the same day as the census of figure 14).

Considerable quantities of fish eggs were taken on these cruises. It was believed that they might throw light on the currents in the bay of Fundy. Mr. R. A. Mackenzie of the staff of the Biological Board, accepted the task of working out this collection for the sake of the information it should provide about the production and distribution of important fishes, such as the cod and haddock. He has kindly sent me a copy of his counts. We are not concerned here with any significance in the study of cod and haddock. As indicators of drift, it is perhaps just worth putting on record that charts for total count in March, April and May provide neither refutation nor confirmation of the suggestion made in the first paragraph of this section, that there may be little circulation in the bay of Fundy at this season.

IX. DISCUSSION OF THE CAUSE OF LOCATION OF THE SARDINE FISHERY

The view has been held that the effect of the proposed dams on the sardine fishery cannot safely be foretold, until the cause has been convincingly established of the remarkable concentration of landings between cape Spencer and cape Elizabeth. The short investigation which we have been able to carry out, has not, in our opinion, established any factor or factors as the cause of this phenomenon, but it is thought that the investigations have added substantially to the revelant knowledge on which our judgment must be based.

There seems little doubt that the availability of herring for such a long season in the gulf of Maine and the bay of Fundy generally has to do with comparatively equable temperature of the water (exemplified by the resulting fog conditions described in section VII). But when the question becomes more particular and we seek for cause of the concentration of landings between cape Spencer and cape Elizabeth, it is much more difficult. Investigation of the conditions which might affect the distribution and survival of the herring has been the concern of my colleagues. Their reports do not show any simple correlation between the factors studied and the location of the sardine fishery. Many fertile suggestions have, however, been made, principally by Dr. A. G. Huntsman, who was good enough to send me an extremely interesting summary of his views, reached as a result of extensive inquiry and investigation.

Before discussing the causes of the concentration of landings the matter of availability for capture should be considered. There is no doubt that a sardine fishery needs canneries and that canneries need a regular supply of sardine herring. In places, therefore, where the occurrence of sardines is only sporadic we must not expect to find any considerable fishery for them. Sardines cannot be transported long distances to a cannery. They must arrive fresh and must have a comparatively undisturbed passage in the hold of the carrying vessel. In St. Mary bay there is no cannery, but sardine herring occur from time to time. In the summer, when the carrying vessels can rely on a smooth passage of the bay of Fundy, considerable quantities may be transported to the canneries on the New Brunswick side. Mr. A. Wentzell of St. Mary bay very kindly gave me an extract from his records of sales in 1928, when he sold no less than 567 hogshead in rather less than a month. (1 hogshead is roughly equivalent to 1,000 lbs.). It appears, however, that the supply has not attracted a factory to St. Mary bay. In the same way the sardine herring are reported by fishermen on the coast of Nova Scotia generally, and occasionally at the head of the bay of Fundy. But there is no special fishery for them, presumably because the supply is insufficient or irregular. The question of whether there are actually more sardine herring in the sea on the strip of coast between cape Spencer and cape Elizabeth than in other parts of the Gulf of Maine, the bay of Fundy or Nova Scotian waters, is open to argument. There is, however, no doubt at all that the mouth of the bay of Fundy, and (in a decreasing degree as we go westwards), the coast of Maine, provide exceptionally good conditions for the *capture* of sardines in weirs. In section IV, figure 7, we saw the particularly rich fishing of areas 13 and 15 near Letite passage, and we now submit additional evidence of this. In figure 16 are shown the weirs with the best reputation, according to the Inspectors of Fisheries in Charlotte county. Three inspectors concerned agreed in placing most of their best weirs in the Letite region, which is remarkable for the combination of very strong tides with highly irregular coast line and many shoals and islands. Examining the chart of figure 9 we see that nowhere in the whole area is there so strong a tide combined with such an irregular coastline, except to the south west of Grand Manan, where also there are many good weirs. The coast of Maine, as far west as cape Elizabeth, is highly indented, but the tides become less strong. It seems from these considerations

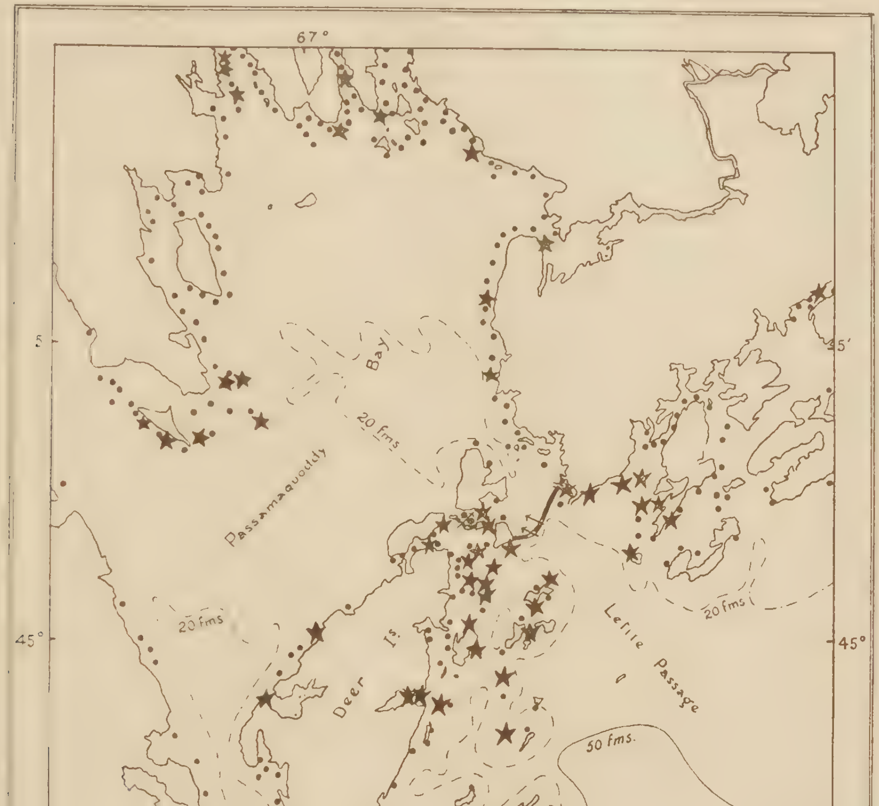

Figure 16. Location of best weirs. Sardine weirs operated in recent years are shown as black dots. Those of best reputation are shown with stars. Three Inspectors of Fisheries gave this information, for districts meeting in Letite passage and it is remarkable how the stars are close to that passage, demonstrating its preponderant richness. (See also figure 7). This is close to the main tide and deep water, and the coast is highly indented and irregular.

that the coast itself may act as a natural trap for herring, and the trap will naturally act more efficiently where there is more interchange of water. Also, more obviously, weir men need sheltered water, provided by the irregular coast line; and the weirs will be more efficient the greater the tides.

We may, therefore, probably discount a proportion of the inequality in the statistical picture, figure 1 (comparing the coast of Maine with the south shore of Nova Scotia), on the grounds of the superiority of the Quoddy-Maine area for catching these sardines. In the present state of our knowledge it would be a brave man who would declare what the proportion of discount should be. It is also uncertain what proportion of the herring population do approach close enough to the shore to be taken in weirs and seines. Dr. Huntsman has suggested (in the manuscript already referred to) that the rise of the sardine fishery was responsible for the dying out of some fisheries for larger herring, by reduction of the stock. Clearly, he seems to think of the sardine fishery as taking a large proportion of the total stock. This matter is, however, open to argument. It is difficult to see why the herring of the gulf of Maine should seek the coast (except at spawning time when they must have clean bottom at no very great depth). Dr. Fish's investigations, including some specially made for this purpose, do not show any particular richness of food in the coastal waters, as compared with outside. Turbidity might, however, make the coast more favourable than the open sea (section VII). We have seen that the water in the sardine area is rather turbid, offering sanctuary to the much pursued herring. On the other hand the herring near the coast is in danger of stranding, or being driven ashore by its enemies, and is in the zone of abundance of the bottom-living gadoid fishes, which are not common in the upper waters of the open sea.

It may be important, that in the sardine area and especially in the Quoddy district, the surface water has been found by my colleague, Dr. Watson, to resemble the middle water of the open bay of Fundy, and it may be a considerable factor in their capture that herring carried to the coast would receive little warning of the nearness of the shore from any temperature gradient. (Against this it must also be admitted that the herring taken in the Quoddy region do not show any particular success if they do, in fact, desire to leave the neighbourhood of the coast after they strike it. This is seen, for example, in the Frye's island catches charted in figure 4, and is specially discussed in section IV).

We may refer to one general deduction that can be made from our own investigations. Firstly, it has already been explained in section V that the fry investigations revealed no concentrated body of very young herring in the mouth of the bay of Fundy, which could be considered as the younger stage of the vast concentration of sardines. Nor did we, immediately after the spawning season, find any significantly greater body of fry from the Grand Manan and other local spawning grounds than we had already sampled during the preceding winter. This suggests that, if there be indeed a concentration of sardine herring, this is a concentration at about the age at which they are caught, of herring from a very wide area. Secondly, the same indication is given by the investigations of length and of cannery purchases, sections III and IV. The fishery, therefore, is not to be ascribed to local production nor to concentration in the passive stage. So we have to seek either (*a*) such conditions as would attract herring, considered as active migrants, to the area, or (*b*) mechanical forces directed towards the area, which may carry the herring passively, combined with conditions in the area such that they do not repel the herring. The gist of Dr. Huntsman's conclusions is that the Quoddy area is favourable for sardines because the movements of the water bring both sardines and their food to the area, without removing them to the same extent. This is not the place for discussion of Dr. Huntsman's theory, and the hydrological and planktological considerations involved are rather the concern of my colleagues than mine. But we should note that if Dr. Huntsman's theory be correct, the placing of dams in the area, where a great mixing now takes place, would tend to produce the double effect of reducing the concentration of sardines in the area and of reducing the supply of food. However, according to a preliminary typescript summary of Dr. Watson's investigations, the effect foreseen by Dr. Huntsman is at any rate not expected to be of great magnitude. Neither effect would be expected seriously to reduce the total survival of herring in the sea. A further effect, of reducing the total amount of phosphates and nitrates made available for plant growth, is considered by my colleagues, Dr. Gran and Mr. Braarud, who do not anticipate any noticeable effect outside the Quoddy region.

X. SUMMARY. EFFECT OF THE PROPOSED DAMS

1. From September 1931 to November 1932 observations were made in the area of the sardine fishery and the sea between Boston and Liverpool, Nova Scotia. The information collected, and published statistics, were studied during the winter of 1932-1933 (section I).

2. The fishery for sardine herring (caught in weirs) is described, and shown to be partly dependent on extremely local conditions and affected by factors of which we are ignorant. Very productive and very poor weirs may be close to one another and spring and fall weirs may be within a mile of each other in the same bay (section II). (Between cape Spencer and cape Elizabeth is called the "Sardine Area").

3. Study of length measurements of sardines shows that herring first appear in the catches at about 12 months old, in August, and grow until October. Certain areas tend to have larger or smaller sardine herring. Sardine herring are generally segregated into shoals of similar length (within an age-group). Study of the occurrence of particular shoals (as characterised by length) indicates supply to weirs of herring from an extensive body in the more open sea (section III).

4. Study of special statistics of cannery purchases emphasizes the richness of the neighbourhood of Letite passage. Sporadic productivity in restricted localities is shown, and attributed to penning of the herring by enemies, such as silver hake (*Merlucius*) and dogfish. An impression of the stability of a limited part of the stock and a mass migration of the remainder is suggested by these statistics, but, no great reliance is placed upon this, for the statistics may well

be readable some other way; this impression is, however, consonant with the findings of section III, above (section IV).

5. Special investigation of the stage when herring fry are small, and presumably passive drifters in the sea, revealed no special supply to the sardine area. On the contrary , the bay of Fundy was poorly supplied (although probably containing the total product of its own spawning grounds); whereas an extensive body of fry off and around cape Sable would probably be directed to the sardine area at a later stage, when, however, they undoubtedly could swim against the current (sections V and VI).

6. Only turbidity was found to be a possible physical factor which might render the sardine area specially attractive to herring. On the other hand the prevailing circulation of water in the gulf of Maine passes through the sardine area (section VII).

7. Euphausiids at the surface form one of the striking features of the Quoddy region (the heart of the sardine area). Catches show that there are large quantities of these elsewhere in the bay of Fundy, but their capture was irregular. Study (by Mr. A. C. Gardiner) of a collection of plankton made in connection with herring fry catches, results in the conclusion that the principal plankton species then taken (except herring fry and fish ova) behaved in a manner best explained by diurnal quiescence and nocturnal activity. (Forms: *Thysanoessa spp. Calanus spp. Sagitta elegans.*) It seems that the sardine area probably contains adequate food for the herring (section VIII).

8. The disproportion in landings of sardine herring in the sardine area, as compared with the rest of the gulf of Maine, bay of Fundy and Nova Scotian waters (figure 1), is partly to be explained on the grounds of especial ease of capture in the sardine area. But it is uncertain whether there is, nevertheless, a disproportion in the populations in the sea in various areas. Only turbidity has been found in our investigations to be a possible favourable factor in the sardine area, and the coastal region is in other ways obviously unfavourable. Dr. A. G. Huntsman's view is that the movements of water bring both sardine herring and their food to the area, without removing them to the same extent; the effect depending on a strong mixing mechanism and a supply of fresh water (section IX).

9. Truly to foretell the effect of the proposed dams we need more detailed, and more certain, knowledge of the herring, than our brief investigation has supplied. But the above considerations lead to certain conclusions in this matter. It is clear from what we have seen, in paragraph 2, of the extremely local nature of the factors affecting the sardine fishery, that the dams would make considerable havoc of the exceptionally rich fishery in their nighbourhood (paragraph 4). These local effects would be expected to be considerable, although the general tidal effect be comparatively slight. Hachey (1934 b) foresees a definite but slight increase in tidal amplitude. The fishery inside the dams would almost certainly be reduced to negligible proportions, since it seems

dependent on immigration (paragraphs 3-5).* Outside the dams it is not so clear. Considerable changes in the set of the tidal streams may be expected, and, since the fishing of weirs is so locally peculiar (paragraph 2), every little change would be expected to have an effect on the fishery of nearby weirs. Some would be made richer, some poorer. On this basis it cannot be foretold whether the total effect on capture immediately outside the dams would be deleterious or not. But, if Dr. Huntsman is right in relating the Quoddy fishery to tidal mixing (paragraph 8), the effect on the fishery in the Quoddy region would probably be serious; that is, partial interference with the mixing mechanism would reduce the amount of herring and of their food brought to the locality. Even with the dams in place there would, however, be *some* mixing of the bottom and surface waters; and a measure of Dr. Huntsman's effect is not to hand. Going further afield, the apparent independence of the main stock from purely local conditions (paragraphs 3, 4, 5), makes it appear that there is little possibility of a widespread effect, for example, along the coast of Maine, or even seriously at Grand Manan.

*In the Damariscotta river at East Boothbay, Maine, there is a small tidal mill. Herring rarely enter through the sluice gate, according to information collected on the spot. The opening of the gateway is about 12 ft. wide by 10 ft. deep. I am indebted to Captain Greenleaf of the U.S.B.F.V. "Pelican" for calling my attention to this mill and to Mr. T. H. Dorr of the U.S. Fish Hatchery for taking me to see it.

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TABLE I. Temperatures and Secci readings

T_1=Temperature at surface.

Station No.	T_1	Secci	Light on disc
(Passamaquoddy bay to Digby)			
P 1	10.9	4.2	shade
P 2	10.1	7.0	shade
P 3	9.6	6.7	sun
P 4	9.9	6.7	sun
P 5	9.7	4.3	sun and shade (made no difference)
P 6	10.4	4.0	shade
P 7	9.5	4.8	rain
P 8	10.7	12.0	shade
P 9	11.8	12.2	sun
P 10	9.2	7.3	
(Digby to St. Mary bay)			
P 11	8.8	8.7	sun
P 12	9.3	9.2	sun
P 13	9.7	8.1	
P 14	10.3	8.6	sun
(St. Mary bay to cape Sable)			
P 15	13.8	6.9	sun
P 16	14.9	6.5	sun
P 17	15.2	6.3	sun
P 18	11.5	6.2	sun
P 19	9.9	8.1	sun
P 20	11.8	11.6	sun
P 21	10.5	7.1	sun
P 22	10.7	8.6	sun
P 23	12.4	10.3	sun
(St. Mary bay to cape Sable)—*cont.*			
P 24	12.3	11.5	sun
P 25	5.8	14.0	sun
P 26	4.0		
(Cape Sable to Liverpool)			
P 27	5.3		
P 28	6.0		
P 29	7.8		
P 30	9.5	8.0	sun
P 31	5.9	7.9	sun
P 32	6.8	8.8	sun
P 33	7.2	8.9	sun
(Portland to Grand Manan)			
P 34	13.7	9.0	shade
P 35	12.6	5.8	sun
P 36	13.1	7.3	sun
P 37	12.3	5.6	sun
P 38	11.7	5.5	sun
P 39	11.0	5.1	sun
P 40	12.5	6.2	sun
P 41	11.1	6.1	sun
P 42	10.3	6.1	
P 43	9.3	5.0	
P 44	9.5	6.3	sun
P 45	8.5	7.1	shade
P 46	9.3	7.1	overcast
P 47	9.0	6.1	overcast

TABLE II. Herring landings in Fundy and Maine

Landings of herring (including Canadian sardines) per unit of coast length per annum by counties. (Coast measured on a chart 18 nautical miles to the inch)

County	1919	1928	1929	1930	Average
Lunenburg	22	8	31	23	21
Queens	35	6	29	22	23
Shelburne	11	4	13	16	11
Yarmouth	11	14	16	25	17
Digby	10	23	7	10	13
Annapolis	8	33	28	9	19
Kings	3	2	4	5	4
Hants	..	0	0	0	0
Colchester	..	1	0	0	0
Cumberland	0	0	0	0	0
Westmoreland	4	0	0	0	1
Albert	0	0	..	0	0
St. John	43	180	65	49	84
Charlotte	258	300	341	218	279
Washington	157	117	143	127	136
Hancock	69	22	36	33	40
Waldo	97	55	71	2	57
Knox	88	50	169	81	97
Lincoln	47	64	66	65	61
Sagadahoc	5	8	5	13	8
Cumberland (U.S.A.)	31	99	118	116	91
York	..	.	..	1	0
Rockingham	..	..	..	3	1
Essex	24	24	29	11	22
Suffolk	8	35	134	149	82
Norfolk	..	..	..	3	1
Plymouth	24	6	33	11	19
Barnstaple	36	11	23	15	22

Table III. Herring landings in Charlotte and Saint John counties

Average monthly landings of herrings (excluding sardines) in Charlotte county and Saint John county based on Inspectors' monthly returns 1920-31 for Charlotte county and 1928-31 for Saint John county excluding 1923 and 1924 except for western Charlotte, and excluding 1920 and 1922 for western Charlotte. (1,000 lb., 454 kg., lots.)

	Grand Manan	Campobello and W. Isles	Eastern Charlotte	Western Charlotte	Saint John county
January	30	43	56	3	1
February	118	8	35	3	2
March	216	22	37	..	3
April	104	139	64	5	nil
May	48	175	38	45	nil
June	56	175	31	22	nil
July	545	436	63	21	nil
August	3766	442	108	18	85
September	6238	629	79	152	221
October	2307	317	45	148	105
November	361	164	8	113	57
December	50	200	6	12	nil

Table IV. Sardine landings in Charlotte and Saint John counties

Average monthly landings of sardines in districts of Charlotte county and Saint John county based on Inspectors' monthly returns 1920-31 for Charlotte county, and 1928-31 for Saint John county excluding 1923 and 1924, except for western Charlotte. Hogsheads (roughly equivalent to 1,000 lb., or 454 kg.).

	Grand Manan	Campobello and W. Isles	Eastern Charlotte	Western Charlotte	Saint John County
January	nil	8	3	nil	nil
February	nil	nil	nil	nil	nil
March	nil	nil	56	nil	nil
April	37	360	542	110	nil
May	55	1300	758	923	15
June	201	986	701	654	44
July	374	1280	787	874	314
August	977	2737	1497	1264	2153
September	753	2205	1677	2095	2429
October	2624	895	945	1548	966
November	274	412	357	282	48
December	2	111	7	27	nil

TABLE V. Sales (in tenths of a hogshead, say 100 lb. lots) of herrings from weirs of the Frye's Island Corporation (By courtesy of Messrs. Connors Bros.)

	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Birch Head									
1928..........	Nil	89	Nil	235	1000	1075	152	164	Nil
1929..........	Nil	139	55	49	25	179	42	Nil	Nil
1930..........	36	727	Nil	Nil	133	23	Nil	Nil	Nil
1931..........	192	90	49	Nil	70	35	Nil	Nil	Nil
1932..........	6	114	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total.......	234	1159	104	284	1228	1312	194	164	Nil
Average.....	47	232	21	57	246	262	39	33	Nil
Bar Weir									
1928..........	Nil	137	91	59	65	Nil	Nil	95	Nil
1929..........	5	345	43	66	242	150	Nil	Nil	Nil
1930..........	83	1505	159	Nil	Nil	Nil	Nil	Nil	Nil
1931..........	420	50	85	581	280	Nil	Nil	Nil	Nil
1932..........	68	364	Nil	Nil	Nil	145	Nil	Nil	Nil
Total.......	576	2401	378	706	587	295	Nil	95	Nil
Average.....	115	480	76	141	117	59	Nil	19	Nil
Fox Island									
1928..........	Nil	574	106	93	165	Nil	55	Nil	Nil
1929..........	26	255	58	168	35	120	Nil	Nil	Nil
1930..........	53	1112	200	Nil	Nil	Nil	Nil	Nil	Nil
1931..........	204	50	125	407	Nil	Nil	Nil	Nil	Nil
1932..........	Nil	378	254	Nil	Nil	178	Nil	Nil	Nil
Total.......	283	2369	743	668	200	298	55	Nil	Nil
Average.....	57	474	149	134	40	60	11	Nil	Nil
Calef Beach									
1928..........	Nil	Nil	Nil	80	835	1820	445	1035	355
1929..........	Nil	Nil	Nil	Nil	683	1054	4	Nil	Nil
1930..........	140	459	288	Nil	120	547	60	Nil	Nil
1931..........	Nil	Nil	Nil	438	1888	540	Nil	Nil	Nil
1932..........	Nil	Nil	Nil	Nil	70	1195	Nil	Nil	Nil
Total.......	140	459	288	518	3596	5156	509	1035	355
Average.....	28	92	58	104	719	1031	102	207	71
Tarpot									
1928..........	Nil	Nil	Nil	15	330	1370	50	279	Nil
1929..........	Nil	Nil	Nil	Nil	Nil	140	Nil	Nil	Nil
1930..........	Nil	Nil	Nil	Nil	38	497	100	Nil	Nil
1931..........	Nil	Nil	Nil	Nil	206	320	Nil	21	Nil
1932..........	Nil	10	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total.......	Nil	10	Nil	15	574	2327	150	300	Nil
Average.....	Nil	2	Nil	3	115	465	30	60	Nil

TABLE V.—*Continued*

	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Cumberland Shore									
1928..........	Nil	520	97	241	2165	115	570	2121	Nil
1929..........	366	1439	Nil	233	316	1925	89	Nil	Nil
1930..........	2131	1384	110	Nil	370	352	Nil	Nil	Nil
1931..........	1756	787	270	768	537	400	Nil	Nil	Nil
1932..........	80	1008	23	77	306	1676	Nil	Nil	Nil
Total.......	4333	5138	500	1319	3694	4468	659	2121	Nil
Average.....	867	1028	100	264	739	894	132	424	Nil
Eagle Island									
1928..........	Nil	431	Nil	Nil	655	95	Nil	Nil	Nil
1929..........	140	314	45	355	307	655	Nil	Nil	Nil
1930..........	572	369	74	Nil	Nil	Nil	Nil	Nil	Nil
1931..........	461	791	156	375	254	100	Nil	Nil	Nil
1932..........	50	666	12	Nil	Nil	518	Nil	Nil	Nil
Total.......	1223	2571	287	730	1216	1368	Nil	Nil	Nil
Average.....	245	514	57	146	243	274	Nil	Nil	Nil
Charlie's Cove									
1928..........	Nil	808	111	166	422	155	Nil	134	44
1929..........	109	1073	Nil	25	47	8	Nil	Nil	Nil
1930..........	568	626	40	Nil	142	298	Nil	Nil	Nil
1931..........	338	459	114	105	210	Nil	Nil	Nil	Nil
1932..........	25	77	38	5	Nil	205	Nil	Nil	Nil
Total.......	1040	3043	303	301	821	666	Nil	134	44
Average.....	208	609	61	60	164	133	Nil	27	9
Mill Cove									
1928..........	Nil	260	72	72	224	740	120	101	42
1929..........	42	601	14	45	182	12	Nil	Nil	Nil
1930..........	489	1170	207	Nil	Nil	154	Nil	Nil	Nil
1931..........	412	461	86	206	169	Nil	Nil	Nil	Nil
1932..........	120	274	117	101	375	772	Nil	Nil	Nil
Total.......	1063	2766	496	424	950	1678	120	101	42
Average.....	213	553	99	85	190	336	24	20	8
Gooseberry Bar									
1928..........	Nil	798	109	Nil	870	337	Nil	180	12
1929..........	57	478	68	301	481	Nil	Nil	Nil	Nil
1930..........	94	1156	233	Nil	Nil	Nil	Nil	Nil	Nil
1931..........	425	355	41	47	Nil	Nil	Nil	Nil	Nil
1932..........	208	160	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Total.......	784	2947	451	348	1351	337	Nil	180	12
Average.....	157	589	90	70	270	67	Nil	36	2

TABLE VI. Example of data on length of sardine herring, and treatment (Extract for week ending Sept. 17th, 1932)

B. Blacks harbour. L. Lubec.

Date 1932 Sep	Observer	Area	Frequency in 1 cm. length-groups																								"Peaks" (cms.)
			6-	7-	8-	9-	10-	11-	12-	13-	14-	15-	16-	17-	18-	19-	20-	21-	22-	23-	24-	25-	26-	27-	28-	29-	
11	L	46													4	11	11	22	16	26	13	11	1	2		1	21, 23
11	L	16					4		2				2	1	9	26	28	13	12	18	11	5	1	1		1	20, 23
11	L	46												2	11	15	31	28	16	11	12	10	1	1			20, 24
12	B	3				13	35	37	15	9		1		1	2	8	3	1	2	3	5	3					11, 19, 24
12	B	15				9	22	45	16	3	9	2	1		1												11, 14
12	B	13									2	5	1	9	20	28	15	5	6	2	4	2					19
12	B	7										3	4	10	18	30	11	11	4	4	3	1					19
12	B	12											1		1	3	6	2	8	8	15	25	1	1	4	•	25, 28
12	B	36											3	2	5	25	32	8	8	6	3			2			20
13	B	15				4	36	40	31	3	1	1				4	2	2	1	3							11, 19
13	B	12					8	13	20	24	24	31	23	19	10	2	1	1		1							15
13	B	12-13										1	4	9	5	15	20	19	13	16	8	6	3				17, 20, 23
13	B	†				34	56	35	30	1																	10
13	B	36											1	4	19	27	23	10	3	5	1	2	1				19
13	B	28												5	11	27	20	13	4	4	5	1	2	1			19
13	L	45										1	2	7	25	57	31	17	9	6	4	3					19
14	L	45											1	9	22	29	13	18	8	9	10	6	3				19, 24
14	L	1	1		2	11	46	45	16	1	1	15	5	8	1	5	6										10½, 15, 20
14	B	15				19	38	50	35	10	2	1	1			2	4										11, 20
14	B	33										1	1	17	41	25	12	7									18
14	B	13											2	5	4	4	12	7	9	15	9	12	2		1		20, 23, 25
14	B	14,36,37							1			1		5	16	27	13	6	7	4	9	3		1	2	3	19, 24
15	B	15,26,28								1			2	14	34	20	14	10		1							18
15	B	n.d.										1		6	13	29	22	7	3	2	3	4		1			19
16	B	15,26,28						1	2		2	8	32	55	25	4	2	2		3							17
16	B	33									2	15	30	35	14	9	9	4									17
16	B	13												2	4	6	5	5	10	15	9	10	1	3		1*	19, 23, 25
16	B	15,16										1	4	13	27	32	22	2	1	1	2	2					19, 24
16	B	14											1	4	10	25	20	13	8	2	4	3					19
16	B	16				10	28	42	30	8	12	3			5	8	5	1	1	3							11, 14; 19
16	L	46												6	7	33	13	11	13	14	7	5	1				19, 23
16	L	45												7	16	18	25	18	15	12	7	10	1				20, 25
17	B	13											3	8	20	27	29	9	7	2	2	7					20, 25

† "Deer Island" * 1 at 30- cm. n.d. Not distinguished.

• 2 at 31- cm.

TABLE VII. Occurrence of length "peaks" of sardine herring in 1932

In the following table "peaks" in the length-distribution in all samples of sardine herring measured by two observers (one at Blacks harbour, the other at Lubec and Eastport), are classed as "main", that is the best represented peak in a sample, or "secondary", when higher peaks occurred in the same sample. Determination of peaks can be followed in table VI, which includes an extract of the original data. In the table below the position of peaks is given to the nearest centimetre. A correction of plus 0.5 cm. is applicable throughout. "Areas" are shown in figure 5.

Week ending	Area	Main peaks	Secondary
Aug. 13......	7	18.	15.
	8	22.	19.
	15	17.	
	23	20, 21.	23.
Aug. 20......	5	16.	
	7	16, 2 at 17, 18.	
	20	20.	
	23	22.	19.
Aug. 27......	1	19, 21, 22.	16, 18, 19.
	7	18.	22.
	23	20, 2 at 22.	23.
	40-44	17, 22.	19, 21.
Sept. 3......	1	10, 15.	15.
	7	4 at 18, 5 at 19, 21.	21, 22, 2 at 23.
	8	19.	23.
	12	23.	
	13	23.	
	15	10.	
	23	24.	20.
	38	22.	
	46	6 at 19.	22, 23, 25.
Sept. 10......	5	10, 11, 18, 19.	17, 25.
	7	18, 7 at 19, 2 at 20.	16, 20, 2 at 22, 23, 24, 25.
	12 and 13	5 at 24.	
	13	2 at 20.	22, 23.
	15	11.	
	20	2 at 20.	
	46	5 at 19, 22.	

Week ending	Area	Main peaks	Secondary
Sept. 17......	1	11.	15, 20.
	3	11.	19, 24.
	7	19.	
	12	15, 25.	28.
	13	19, 20, 2 at 23.	19, 20, 3 at 25.
	14	19.	
	15	4 at 11.	2 at 14, 2 at 19, 20.
	16	20.	23.
	28	19.	
	33	17, 18.	
	36	19, 20.	
	45	2 at 19, 20.	24, 25.
	46	19, 20, 23.	21, 23, 24.
	12 and 13	20.	17, 23.
	15 and 16	19.	24.
	15, 26 and 28	17, 18.	
	14, 36 and 37	19.	24.
	N.D.	10, 19.	
Sept. 24......	7	2 at 11, 18, 2 at 19, 20.	11, 12, 15, 16, 19, 25.
	14	2 at 19, 2 at 20.	10, 18, 24, 25, 27.
	15	12, 18.	19.
	16	2 at 11, 12.	15.
	26	2 at 19.	
	33	11.	17.
	46	19.	
	15, 16, 17, 18, 26 and 28	12, 19.	18.
Oct. 1......	5	12.	
	11	19.	23.
	14	20.	17.
	15	2 at 12.	
	16	11.	
	23	2 at 20, 3 at 21, 23, 25.	3 at 23, 25.
	34	11, 12.	
	35	10.	
	46	2 at 20.	23, 24, 25.
	15, 16, 17, 18, 16 and 28	13.	
Oct. 8......	14	2 at 18, 19, 20.	20, 12.
	15	11, 2 at 12, 2 at 13.	2 at 16, 18, 19.
	16	2 at 10, 12.	17.
	20	11.	15, 19.
	23	5 at 21, 22.	
	26	2 at 19.	
	32	11, 2 at 12.	
	34	2 at 11, 9.	16, 12.
	35	11.	
	36	2 at 10, 12, 19.	27.
	46	2 at 19.	

Week ending	Area	Main peaks	Secondary
Oct. 15......	14	18, 4 at 19.	15, 25.
	15	12.	
	17	19.	
	23	2 at 21, 22, 23, 3 at 24.	21, 22, 23.
	26	12, 13, 18, 2 at 19.	13, 14, 16, 22.
	32	11, 12.	16.
	33	2 at 10.	
	34	10, 2 at 11.	
	46	22.	25, 28.
	15 or 23	12.	19.
	41, 43, 44	25.	22.
Oct. 22......	14	18.	12.
	15	10, 3 at 12.	20.
	16	19, 20.	12, 13.
	17	11, 12.	
	23	2 at 21, 22.	2 at 24, 25.
	26	12, 13, 18, 2 at 19, 20	2 at 12, 18, 19, 25.
	32	11.	
	35	2 at 11.	
	42	12.	
	41, 43, 44	21, 2 at 24, 25.	2 at 12, 16, 19, 22.
	15 and 17	12.	19.
	15, 16 and 17	12.	23.
Oct. 29......	14	11.	
	18	20.	13, 16.
	23	21, 2 at 24.	2 at 22, 23, 27, 29.
	26	18, 19.	
	27	2 at 13.	
	15-17	13.	
	18 and 26	19.	12, 22.
Nov. 5......	15	11, 3 at 12, 2 at 13, 2 at 14.	2 at 18, 2 at 19, 20, 21.
	18	21.	13, 25.
	23	2 at 22, 23.	13, 20, 25.
	26	2 at 12, 2 at 19.	12, 15, 2 at 20, 24.
	27	2 at 13, 14.	18.
	16, 17	13.	17.
	12, 14	2 at 12.	
	41, 43, 44	22, 25.	
Nov. 12......	14	10, 11, 19.	10, 2 at 19.
	15	2 at 10, 3 at 11, 2 at 12.	2 at 18.
	16	11.	
	22	22.	12.
	27	2 at 13.	16, 18.
	17, 18, 26, 28	19.	23.
	15, 16, 17, 18, 26 and 28	11.	15.
	N.D.	11.	

Week ending	Area	Main peaks	Secondary
Nov. 19......	14	2 at 18.	10, 11.
	15	6 at 11, 12.	
	16	10, 12.	19.
	18	13.	19.
	22	2 at 21.	19, 2 at 25.
	23	20.	13, 23.
	26	12, 13.	11, 15, 2 at 18, 23.
	27	12.	
	15, 16, 17, 18, 26 and 28	11, 13.	10, 25.
Nov. 26......	14	10.	
	15	3 at 11, 2 at 12.	19.
	16	10, 11, 12.	2 at 19, 22.
	18	2 at 12, 13.	15, 18.
	22	18.	16, 21, 26.
Dec. 3......	15	10, 2 at 11, 12. 13.	
	16	3 at 11, 3 at 12, 14.	13, 17.
	18	12, 2 at 13.	16.
Dec. 10......	15	3 at 11, 12.	
	16	2 at 11, 12, 13.	
Dec. 17......	15	3 at 11, 12, 13.	
	16	12, 13.	

TABLE VIII. Length of sardines, 1932

The table gives the number of occurrences of peaks in length-frequency distributions arranged by fortnights and centimetres length. 0.5 should be added to the length (which was measured to the "cm. below"). Samples (from Blacks harbour, Lubec and Eastport) of all purchases reaching the factories where the two observers were stationed. Measuring only began in August.

Number of peaks at (cm.):	Fortnight ending:									
	Aug. 20	Sept. 3	Sept. 17	Oct. 1	Oct. 15	Oct. 29	Nov. 12	Nov. 26	Dec. 10	(Dec. 16)
9	..	..	..	..	..	..	..	..	..	..
9	..	..	..	..	1	..	..	..	..	..
10	..	2	2	2	7	1	4	5	1	..
11	..	..	8	8	9	5	8	13	10	3
12	..	..	..	8	12	15	11	9	7	2
13	..	..	..	1	4	6	9	5	5	2
14	..	..	2	..	1	..	3	..	1	..
15	1	2	2	2	2	..	2	2	..	..
16	2	1	1	1	5	2	1	1	1	..
17	3	1	4	2	1	..	1	..	1	..
18	2	6	4	4	5	4	6	6	..	..
19	2	15	28	11	16	8	8	6	..	..
20	2	2	16	8	2	4	4	1	..	..
21	1	4	1	3	8	4	2	3	..	..
22	2	8	4	..	6	5	4	1	..	..
23	1	7	8	6	2	2	2	2	..	..
24	..	1	11	2	3	6	1	..	..	..
25	..	1	7	5	3	3	3	3	..	..
26	..	..	..	..	..	..	..	1	..	..
27	..	..	..	1	1	1	..	..	..	..
28	..	..	1	..	1	..	..	..	..	..
29	..	..	..	..	..	1	..	..	..	..
Total......	16	50	99	64	89	67	69	58	26	7

Table IX. Comparison of sardine fishery in Quoddy and Grand Manan

Q. "Quoddy". Areas 12-18, 22-37.
G.M. Grand Manan. Areas 39-44, 50.

1927			1929		
Fortnight ending	Q	G.M.	Fortnight ending	Q	G.M.
May 22	16	0	Mar. 30	14	0
June 5	52	0	April 13	30	1
19	35	1	27	45	9
July 3	30	0	May 11	134	0
17	102	3	25	145	2
31	102	4	June 8	116	3
Aug. 14	118	2	22	108	8
28	93	3	July 6	49	8
Sept. 11	74	0	20	104	8
25	97	0	Aug. 3	70	9
Oct. 9	71	0	17	120	11
23	64	3	31	65	0
Nov. 6	82	4	Sept. 14	107	12
20	71	0	28	129	11
Dec. 4	48	0	Oct. 12	106	5
			26	56	10
			Nov. 9	25	1
			23	12	3

TABLE X. Hours of fog recorded at Light Stations in July 1930, 1931
(By courtesy of Canadian and U.S. Marine Departments)

	1930 Hours	1931 Hours
Cape d'Espoir	51*	93†
East point	37*	39†
Entry island	56*	99†
Cape north	73	123
Flint island	130	246
Cranberry island	220	445
Beaver island	328	446
Sambro	319	292
Halifax (Sambro) lightship	208	288
Cross island	350	376
Cape Roseway	480	446
Seal island	246	403
Cape Fourchu	342	344
Brier island	292	344
Gannet rock	314	402
Point Prim	137	137
Cape d'Or	313	278
Apple river	201	298
Cape Enrage	206	301
Cape Spencer	299	362
Lepreau	224	353
Long Eddy point	253	354
Letite passage (Mascabin (Green) pt)	237	316
Head harbour (East Quoddy)	295	355
West Quoddy head	299	439
Libby islands	323	359
Egg rock	96	145
Petit Manan	203	308
Mount Desert	209	265
Matincus rock	101	188
Owls head	93	243
Seguin	96	244
Cape Ann	40	128
Cape Cod	25	165
Vineyard sound	47	188
Block island S.E.	39	232
Great Salt pond	22	154
Montauk point	62	207
Sandy Hook	23	32
Fenwick island	0	41

*For the year 1929. †For the year 1930.

Contribution No. 97

On the Probable Relationship Between Vertical Stability and Lateral Mixing Processes.

By

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[1] Joint contribution from the Woods Hole Oceanographic Institution (No. 97) and from the Bingham Oceanographic Laboratory.

IN a separate paper the writer has had opportunity to report on a series of hydrographic observations in the Caribbean Sea (Parr 1936). Although they do not warrant designation as evidence on this point, some of the data forming the basis of that report do at least suggest the possibility, among others, that lateral mixing between adjacent "streaks" of current may be least extensive in the layers of least vertical stability. The writer has consequently become interested in the problem of the theoretical relationship between lateral mixing and vertical stability.

If we assume that the components of turbulent energy perpendicular upon the axis of the current are equally distributed in all directions the end points of potential turbulent movements in a homogeneous body of water would form a perfect circle. With vertical stratification in point of density the vertical components of motion produced by an equal force would obviously be reduced, while the horizontal components should *ceteris paribus* remain unaltered, and the end points of turbulent movements around the axis of flow might be expected to form an ellipse with a horizontal long axis of the same length as the diameter of our circle. Up to this point our conclusions have already been taken into consideration in meteorology by Taylor (1917, 1927, 1931).

But from actual observations in the lower atmosphere, Taylor has come to the conclusion that "all three components are reduced equally" so that the sphere of turbulence "is merely reduced in radius when a stabilizing density gradient exists" and "is not altered into an ellipsoid" (Taylor 1931, *loc. cit.*, p. 42). These observations and conclusions of Taylor's, however, refer only to atmospheric eddy movements of a relatively low order of magnitude with a frequency of change often to be reckoned in numbers of fluctuations per minute. But when we are dealing with mixing processes in large volume between adjacent water masses we are also, and perhaps even mainly, concerned with a larger pattern of eddy motion on a much higher order of magnitude, which in Taylor's observations would correspond to the changes in the *mean* wind over periods of hours (or perhaps even days) whereas Taylor's conclusions refer only to the singularities of wind variations of high frequency and correspondingly low order of magnitude.

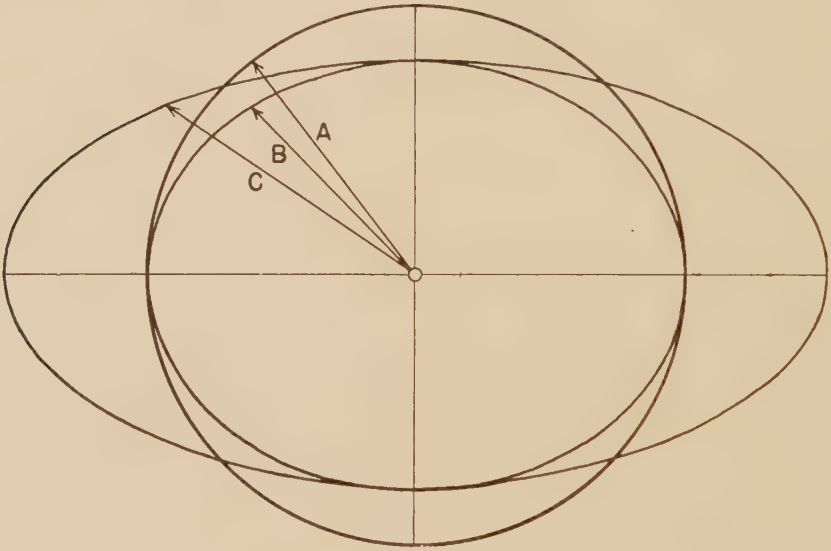

Figure 1.
Probable change of circular boundary of turbulent motion in a homogeneous fluid to an elliptic boundary with horizontal axis longer than the diameter of the circle in a vertically stratified fluid.

But in this turbulence pattern of higher order with which we are concerned in lateral oceanic mixing processes we are dealing with the irregular movements, as single units (only gradually disintegrating), of large bodies of water to be reckoned in cubic metres, decametres, hectometres or perhaps even cubic kilometres. And for the horizontal movements of such bodies of water we may carry our conclusions in regard to the probable distortion the circle of turbulent motion to an ellipsoid under conditions of vertical stability one step further *since it is evident that the reduction of the vertical components of turbulence (of all orders of magnitude) caused by this vertical stability also*

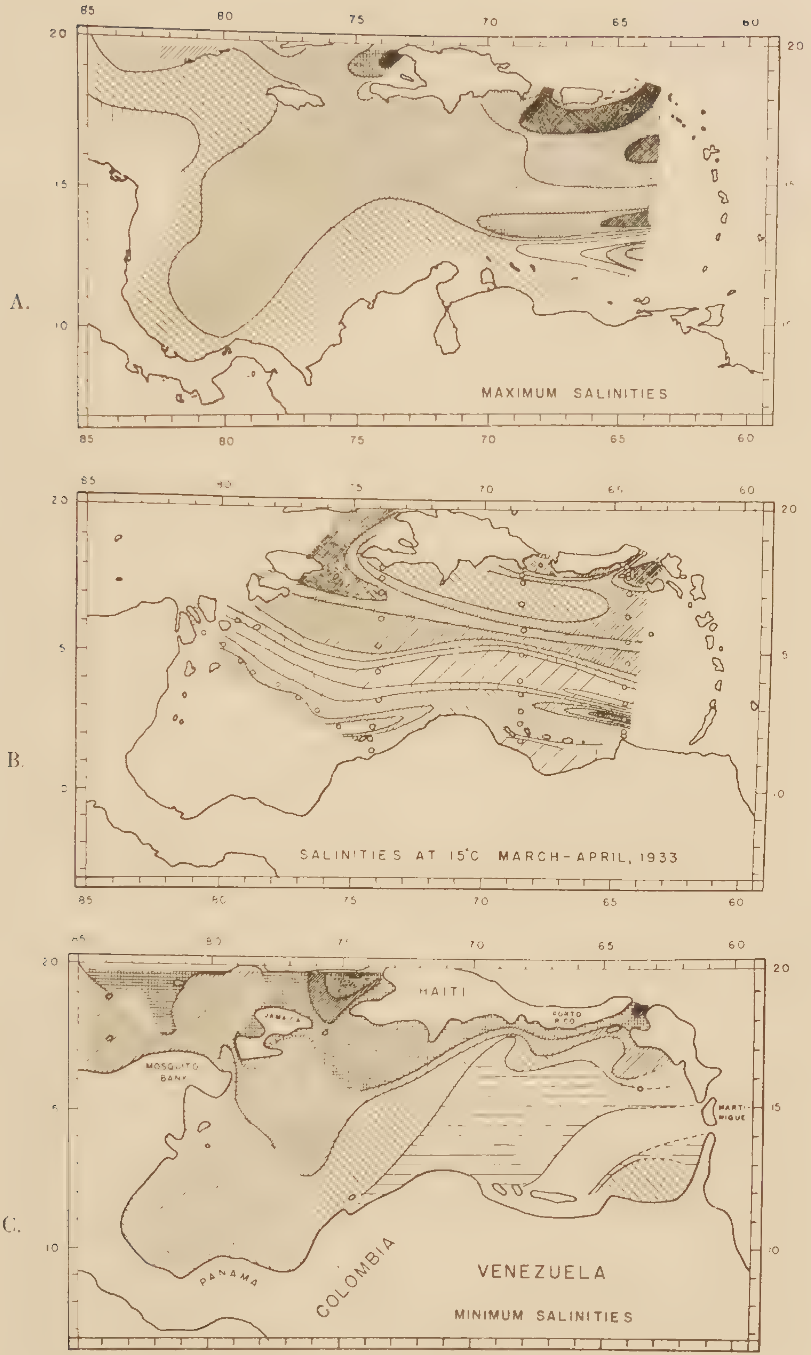

Figure 2. (For legends see p. 311, bottom).

reduces the vertical transfer of momentum or, in other words, the frictional resistance to the horizontal movements in the eddy patterns of higher orders of magnitude. The horizontal components of actual motion resulting from an equal force in the larger eddy patterns should thus not only be expected to remain unaltered but to be positively increased by vertical stability. Our circle of turbulent movements in an homogeneous fluid will not only be distorted to an ellipsoid with horizontal axis equal to the diameter of the circle, but with a much longer horizontal axis. The three steps in our deductions are diagrammatically illustrated in our Figure 1, the arrows A, B, and C representing singularities of movement resulting from the identical force according to each deductive step.

From these considerations we arrive at the principle that *vertical stability, while reducing the vertical mixing processes which are only of relatively very low orders of magnitude must also increase lateral mixing along isopycnal surfaces on a tremendously much larger scale in the horizontal eddy patterns of higher orders of magnitude.* Considering the cumulative effect of eddy patterns of all orders of magnitude involved in oceanic mixing processes it is thus evident that vertical and lateral stability must be in inverse relationship to each other. From these abstract considerations we may now turn our attentions to an actual set of observations from the Caribbean region which apparently provides an illustration and confirmation of our conclusions.

The waters of the Caribbean must obviously enter as many separate streaks of current through the various passages in the chain of the Lesser Antillean Islands in the east. Figure 2 shows the persistence or disappearance of these separate streaks in so far as they can be traced by their salinities. It would seem from these observations as though the streakiness of the layer of a temperature of 15° C., in spite of its relatively slight salinity differences, is much more stable and persistent than the streakiness of the maximum salinity layer above, *as well as* that of the minimum salinity layer below. While the streakiness of the latter two would seem to have disappeared at about 70° W. longitude by admixture into a general gradient from north to south, the streakiness of the former remains and extends itself much farther to the westward. A glance at the typical T-S correlation curve for this region (Figure 3) immediately reveals that the layer of 15° C. temperature, which shows such apparent horizontal stability, occupies

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A: Distribution of maximum salinities (about 100—150 metres depth). Contour lines for every 0·1 ‰ salinity from 36·5 ‰ (lightest shading) to above 36·9 ‰ (darkest shading).

B: Distribution of salinities in 15° C. isothermal sheet (about 200—400 metres depth). Contour lines for every 0·025 ‰ salinity from less than 35·90 (lightest shading) to more than 36·00 ‰ (darkest shading).

C: Distribution of minimum salinities (about 600—900 metres depth). Contour lines for every 0·05 ‰ salinity from 35·65 ‰ (dotted area 35·65—35·70 ‰) to 36·00 ‰ (darkest shading).

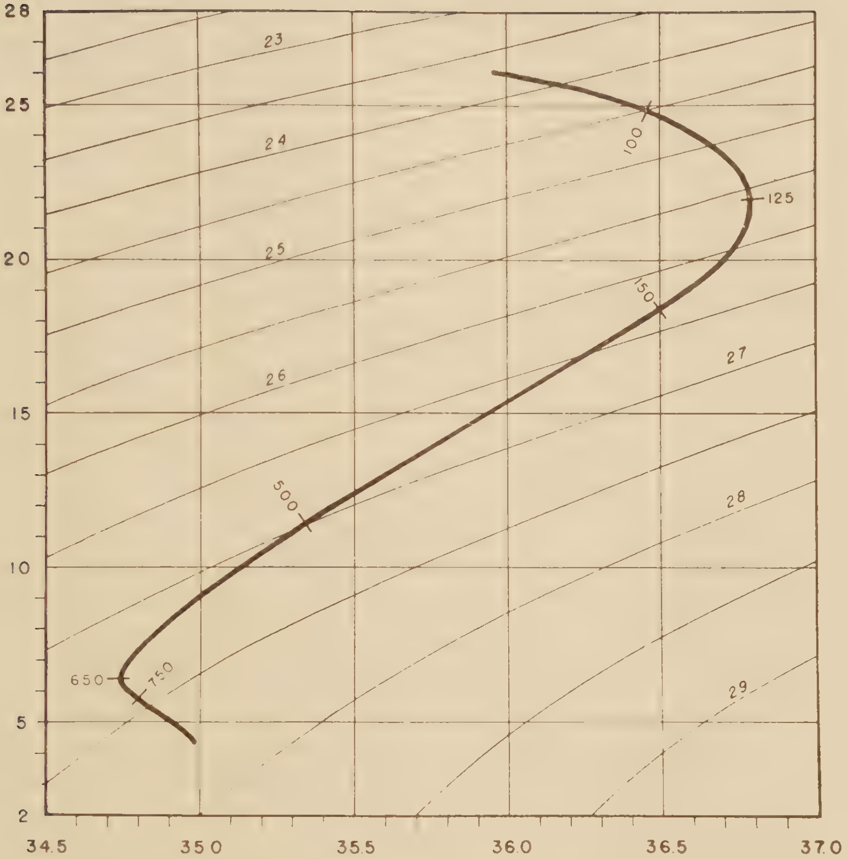

Figure 3.
Average Temperature-Salinity correlation curve for eastern Caribbean. Salinity scale in $^0/_{00}$ at bottom, temperature scale in ° C. at left, oblique isopycnals, and selected approximate average depths in metres marked along the curve.

the centre of the vertically most instable portion of the curve; while the horizontally instable maximum and minimum salinity layers each represent a maximum of vertical stability. The writer is, of course, fully aware that the principle here suggested is, under any circumstance, only one of several causes contributing to the situation shown in our figures, which is the reason why these data cannot be classified as evidence, but they do at least strongly suggest the presence of this factor among the others.

In any event, the logics of its derivation are so simple and obvious, and the observational data, such as they are, so suggestive of its validity, that the writer does not hesitate to assert his belief in the principle that vertical stability must promote lateral mixing, and *vice versa,* and to urge further investigation of this very important question.

An excellent opportunity for such an investigation would seem to be found in the eastern Caribbean and plans to secure a more detailed set of observations for this purpose in the near future are now under consideration.

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The Reflection and Absorption of Daylight at the Surface of the Ocean

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IN previous measurements of the penetration of daylight into the sea considerable doubt has existed as to the magnitude and importance of the light "lost" at the surface of the water through reflection or absorption under the various conditions of sea and sky.[1–10] Attempts to measure the light present just beneath the surface of the water for comparison with that just above the surface have usually been unsuccessful because the action of the waves and the motion of the ship have made it impossible to keep the submarine photometer in the desired position long enough to make a measurement. Furthermore, the light for several meters below the surface fluctuates so rapidly that it is very difficult to obtain a reliable reading at these levels particularly when using the potentiometer method. The result is that the depth of the first point of observation has often not been less than 5 meters in off shore localities and occasionally no satisfactory measurement could be obtained short of 10 m. When the curves representing the penetration of light from the first point downwards are extended upwards to zero depth, it is commonly found that they strike the abscissa at points indicating a reduction in the light at the very surface of from a few percent to 50 or 60 percent. This discrepancy has been termed the "surface loss."[10]

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* Contribution No. 98.

[1] Zenker, *Die Verteilung der Warme auf der Erdoberflache* (Berlin, 1888).

[2] Paul Regnard, *La vie dans les eaux* (Paris, 1891), pp. 204–217.

[3] V. E. Shelford and F. W. Gail, Publ. Puget Sound Biol. Sta. **3**, 160 (1922).

[4] Shelford, Publ. Puget Sound Biol. Sta. **7**, 161 (1929).

[5] H. H. Poole and W. R. G. Atkins, J. Marine Biol. Ass. **15**, 482 (1928).

[6] Poole and Atkins, J. Marine Biol. Ass. **16**, 313 (1929).

[7] Birge and Juday, Trans. Wisconsin Acad. **24**, 574 (1929).

[8] W. R. G. Atkins and H. H. Poole, J. Marine Biol. Ass. **17**, 617–632 (1931).

[9] Atkins, J. Conseil International pour l'Exploration de la Mer **7**, 191 (1932).

[10] Atkins and Poole, Phil. Trans. Roy. Soc. London **B222**, 144–148 (1933).

It was the purpose of the present investigation to determine first of all whether such large surface losses actually exist or whether they can be accounted for by some instrumental or observational error. Secondly it was desired to distinguish the loss due to reflection at the surface from the apparent loss which would be produced by a stratum of less transparent water which might have existed undetected just beneath the surface. Finally it was hoped that some definite relations could be worked out between the amount of surface loss and the degree of roughness of the sea surface, the clearness of the sky, and the altitude of the sun. If this could be done it would be possible to use the transmissive exponent once obtained for a given locality at a given season for calculating the actual irradiation present at any desired depth under any conditions of weather or sea surface from the value of daylight intensity at the surface—either measured on the spot or assumed from standard meteorological observations.

The incident light I at the surface of the sea may be divided into three components; A, that which penetrates the surface and is entirely absorbed in the sea; R, that which is reflected either at the smooth surface of the water or by white foam and bubbles on the surface; and U, that which penetrates the surface but is scattered back by particles and bubbles in the water below and finally returns to the air. Therefore,

$$I = A + R + U.$$

If the sea is covered with foam, the surface must be defined as the surface of the bubbles of the foam.

The magnitudes of the three components A, R, and U may be determined by placing a photometer in various positions relative to the sea surface and comparing the values obtained with I, the intensity found with the receiving surface (a diffusing disk of opal glass) of the photometer placed upwards and horizontal. If the instrument is suspended over the sea in an inverted position, it measures the quantity $R+U$ which is the total light coming upward from the sea's surface. If the photometer is lowered in an inverted position to a point just beneath the surface, U can be measured alone.

The total light passing downwards through the surface is $A+U$, but this quantity cannot be measured directly with precision as already explained. However, since I, U, and $R+U$ can all be accurately measured, the values of A and R alone can be calculated. The quantity $R+U$ is of particular interest as being that fraction of the light falling on the ocean which does not contribute to its supply of energy. The magnitude of this fraction has not been determined previously to our knowledge.* The remaining light, which is the quantity A, is the important component in relation to the ocean water itself. A is absorbed by molecules of water, by bubbles, by suspended particles, and by organisms. This component is the entire source of heat for the ocean (if infrared radiation is included) and is responsible for the photochemical reactions of marine organisms—especially photosynthesis, without which life in the sea would not be possible.

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* Except for a few measurements made from an aeroplane (see below).

The light passing upwards from the surface of the sea fluctuates very rapidly with the motion of the waves. It was therefore necessary to use all possible means to integrate this flicker over time. The first step was to mount the photometers high above the water and far from any obstruction which would cut off the light from the sea. Accordingly a light framework of pipe was constructed in the shape of a triangular pyramid, made buoyant by lashing a barrel to each corner. The sides of the base measured 4.6 m, and the height of the legs was 6.7 m. Framework and barrels were painted black to minimize reflection into the two photometers which were secured in an inverted position at the top of the tower at a vertical distance of about 6 m above the surface of the water. A 23 kg concrete block attached to each corner of the base lowered the center of gravity of the tower so that it could stand a 30° tip without capsizing. Since the tower floated with its triangular pipe base about 20 cm under water, it had very little effect upon the surface of the sea even in the strong winds of Buzzards Bay. The tower with all its equipment weighed about 90 kg and was easily lifted out of the water onto the stern of the power boat, *Asterias*, from which the measurements were made. In this way it was carried to location and then lifted overboard. Two rubber covered cables 100 meters long ran between the two photometers and the recording apparatus on the boat. The tower floated sufficiently far away so that the boat cut off a negligible amount of reflected light.

The performance of the tower was entirely satisfactory. Waves approximately 1.2 m high and a wind of nearly 20 miles per hour tossed it around so little that it was not necessary to mount the photometers in gimbals. Towards the end of the summer some of the pipes had become considerably weakened due to the action of sea water at the joints, and the tower collapsed while being lifted aboard. A tower of similar dimensions but made of angle iron welded at the joints would be much stronger and have the same advantages as the pipe construction.

The photometers employed were those used previously by Oster and Clarke[11] except that the photoelectric cells in the sea photometers were exchanged with those in the deck photometers. The heavy sea photometers were mounted on gimbals and placed facing upwards on deck while the deck photometers were mounted on the tower. The combinations of cells and filters employed covered the "red" region (6000–7000A), and the "violet" region (3100–4500A). The tower photometers were calibrated against those used on deck before each set of observations as previously described.[12]

THE ELECTRICAL CIRCUIT

Since the light from the surface of the water flickers rapidly the "marine potentiometer"[13] which gives an instantaneous value of its intensity could not be used for these measurements. The suitability of the neon discharge-tube photometer[13] was tested by connecting it in series with the potentiometer in order to measure the current by both methods simultaneously as described by J. H. J. Poole.[14] While the potentiometer gave a constant reading to within one percent with the cell under constant illumination, the number of counts from the neon tube varied by at least 10 percent under all conditions of capacity and voltage. The response of the neon tube was found to be nonlinear with change in current which made it impossible to use in a flickering light.

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[11] Oster and Clarke, J. Opt. Soc. Am. **25**, 85 (1935).

[12] G. L. Clarke, Biol. Bull. **65**, 317 (1933).

[13] Gall and Atkins, J. Marine Biol. Assn. **17**, 1017–1028 (1931).

[14] J. H. J. Poole, Sci. Proc. Roy. Dublin Soc. **19**, 17–25 (1928).

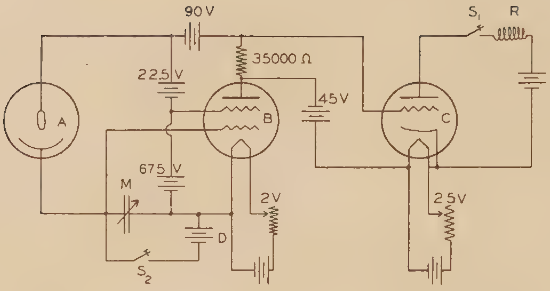

FIG. 1. Circuit employing a Thyratron tube used for integrating variable photoelectric current.

A circuit employing a Thyratron (Fig. 1) was found to be entirely satisfactory. The photoelectric cell *A* is connected in series with a 90-volt battery and a variable condenser *M* with 0.5, 0.05, 0.005, and 0.0005 microfarad capacity. The battery side of the condenser is connected to the filament of a 232 amplifier tube *B*. The other side goes to the control grid of the tube, and also to relay switch S_2. The battery *D* makes the control grid negative when the relay switch is closed. A resistance of 35,000 ohms in the plate circuit of the 232 tube gives a change in voltage between the filament and controlgrid of the 885 Thyratron tube *C*. This tube is filled with a low pressure of argon. When the control grid is negative no current flows in the plate circuit. As the control grid becomes more and more positive it reaches a point where a gaseous discharge takes place between the filament and the plate. The plate current rises to a very high value, and is no longer affected by the grid potential. The plate circuit contains a relay *R* and relay switch S_1.

The circuit operates as follows. The current from the photoelectric cell charges up the condenser *M* until the voltage on the control grid of the 232 tube produces a large plate current. This current increases the voltage across the 35,000-ohm resistance until the grid of the 885 tube starts the discharge. The relay is excited and performs three operations. First it opens switch S_1 thereby extinguishing the discharge in the 885 tube. Second it closes switch S_2 bringing the control grid of the 232 tube back to the voltage determined by the battery D. Third it moves the escapement of a watch so that the second hand records half a second. The whole process repeats itself, and the watch keeps a count of the number of discharges.

To calibrate the circuit in amperes it is necessary to know its capacity with the photoelectric cell connected and the difference between the voltage delivered by D and the discharge voltage. The former is measured by plotting the time for a fixed number of discharges produced by a steady current against various capacities of condenser M. The intersection of the curve with the capacity axis gives the circuit capacity. The discharge voltage can be found by replacing D by a potentiometer.

The precision of the circuit is limited by two factors, first by the range of uncertainty in the tripping voltage, and second by the control grid current of the 232 tube. The latter can be reduced to a minimum by choosing a tube with a low grid current, and the former can be diminished to an unimportant fraction of the whole by increasing the range through which the voltage of the condenser runs. The 885 tube could be used alone except for the fact that the uncertainty in the tripping voltage is about 1.5 volts. Care must be taken that the counts be not too fast as the relay takes about 0.01 second to react and therefore introduces a one percent inaccuracy in counts one second apart. The range of the circuit can be extended by increasing the voltage of C or the capacity M. The leakage current is about 2×10^{-11} ampere and is quite steady so that a current of 10^{-10} ampere can be measured to one percent. The largest current is about 10^{-5} ampere.

The tubes and batteries are mounted in a strong wooden box which is almost air tight and is kept dry inside with activated alumina. The box is opened occasionally to change the capacity *M*. The 885 tube uses a storage battery which plugs into the box and the relay, in a separate box of its own, plugs into the circuit box. The wire from switch S_2 to condenser M enters the relay box through a hard rubber petticoat insulator. In foggy weather it is often necessary to pour very hot paraffin over the insulator and the ends of the leads from the photoelectric cells to stop surface leakage.

Two wires lead to each deck cell, but in the case of the tower cells only one lead goes to each cell from the boat. The other lead is grounded to the tower, and the electrical circuit is completed through the water to a metal electrode hung over the side of the boat. The resistance of the sea water for a distance of 100 meters cannot be more than 200,000 ohms and therefore has no effect on the readings. Care must be taken to standardize with all the cable in the water since the capacity of the circuit changes on submersion.

NEW PHOTOMETERS EMPLOYING RECTIFIER CELLS

Following the general lines of other investigators[15–17] two photometers were constructed by using the Westinghouse Photox Cell (Type SW–30) with a microammeter made by the same company (Type PX–4) and a suitable shunt (Fig. 2). The full-scale reading of the microammeter is 25 microamperes, and the internal resistance for this particular instrument is 297.2 ohms. No. 1 Photox cell was mounted in sea photometer case No. 2 with its face 4 cm from the inside surface of the heavy plate-glass window which was covered on the outside with an opal glass diffusing disk as

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[15] Atkins and Poole, J. Marine Biol. Ass. **19**, 67–72 (1933).

[16] Poole and Atkins, Sci. Proc. Roy. Dub. Soc. **20**, 537 (1933).

[17] Petterson and Landberg, Göteborgs Kungl. Vetenskaps-och Vitterkets—Samhalles Handl. **B3**, No. 7 (1934).

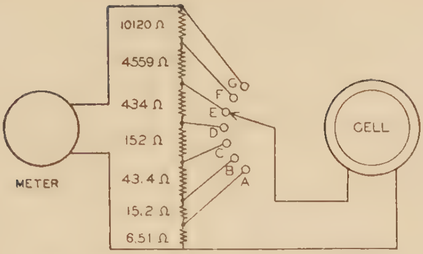

FIG. 2. The circuit for the photometers employing the Photox cell and microammeter showing the connections for the variable shunt.

before. For use on deck a small cylindrical copper box was constructed at the bottom of which cell No. 2 was secured at a distance of 6 cm from the receiving window which consisted of a similar diffusing disk.

The needle of the microammeter is so very highly damped that even in the stormiest weather the effect of the motion of the boat is negligible. It is necessary to have at least 3000 ohms in the external circuit to avoid over damping the needle. This has the disadvantage of demanding high resistances in the shunt and the external circuit of the Photox cell except when the shunt is set at *G*. Consequently the current-intensity curve deviates very markedly from a straight line, and at high intensities runs almost parallel to the intensity axis. To avoid using this part of the curve a diaphragm was placed on top of the diffusing disk of each photometer whenever the intensity demanded it. As a result only shunts *E*, *F*, and *G* need be used.

The spectral sensitive of our Photox cells has not been specially determined, but since the manufacturer reports that these cells do not vary greatly, it seems safe to use the published average curve.[18] The average sensitivity curve shows a maximum at 5500A, dropping off to values of ten percent of the maximum at 4650A and 6250A, and therefore corresponds closely with the "green" region investigated by Oster and Clarke.[11]

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[18] Westinghouse Instruments Catalog, Section 43–705, 1935.

Photox cell No. 2 was calibrated for each setting of the shunt by comparing its response with that of the vacuum photoelectric cell[19] used on the tower, but with the green filter (4900–6200A) used previously. The cells to be compared were placed so that they received the same amount of light from two 500-watt bulbs. This was checked by exchanging their positions. The currents from both cells were measured simultaneously, and then the cells were moved further away from the lights so that the intensity changed by the same amount for both cells, and the currents measured again. Three separate graphs were made of the Photox cell current against the photoelectric cell current corresponding to the three settings of the shunt, E, F, and G. By means of these curves referring the nonlinear response of the Photox cell to the linear one of the vacuum cell, the determination of all relative intensities with the Photox cell is made possible. The calibration was accurate to within 1.5 percent.

Photox cell No. 2 was then placed beside No. 1 and diaphragms chosen which made both give the same current. When moved together away from or towards the light, the two currents were always equal to each other. This showed that the emission of cell No. 1 followed the same curve as that for cell No. 2. A further test was made to ascertain whether the position or size of the spot of light falling on the diffusing disk had any effect upon the response of the cells. A lens was set up in front of a 500-watt lamp so as to bring the image of the filament to a focus in space. The cells were moved about in the beam of light in such a way that the luminous flux striking the diffusing disk always remained the same, but the size and position of the spot of light varied over all possible cases. No change in current was observed so long as the total luminous flux remained the same.

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[19] As an added precaution all four vacuum cells were tested for their linearity of response to intensity in the following manner, H. Kreusler, Ann. d. Physik 6, 412 (1901)). A lens focused the light from a 500-watt lamp on the photometer diffusing disk. Two doors were placed between the photometer and the lens close to the lens. When both doors are open the brightness of the image on the diffusing disk is I. With door 1 closed the brightness is I_2 and with door 2 closed it is I_1. With both closed the light coming through the crack between them gives a brightness I_b. The optical arrangement makes $I = I_1 + I_2 - I_b$. If the cell is linear then the corresponding currents will add. The method has the advantage that it is not necessary to know what the various intensities are but only whether the corresponding currents add. All four photoelectric cells were found to be linear to within 1 percent.

Since rectifier cells are known to be affected by temperature changes, the emission of the sea photometer was tested at 26.7°C, 20.5°C, and 12.0°C under three illuminations covering the range of intensities met with in actual use. The greatest deviation found was an increase in emission at 12.0°C over that at 26.7°C of 13 percent under conditions of high illumination. Changes in temperature of this magnitude are not ordinarily encountered during any one series of measurements at sea. However, in those cases in which the temperature of the air is significantly different from that of the water, this source of error is avoided by allowing the sea photometer to cool down to the temperature of the water before beginning the measurements.

The Photox deck photometer was standardized against a 1000-watt incandescent lamp of known emission in the same manner as previously described.[12] The limits of spectral sensitivity of this photometer were arbitrarily taken as 4650A and 6250A. The irradiation within this range at a distance of 1 meter from the lamp is $310\mu w/cm^2$ (about 1500 meter candles*) and produced a current of 13.5μ amp. with shunt *F*. Through the use of the relative calibration curves already described the intensity of light corresponding to any reading of the instrument can be determined in absolute units. The weakest light that can be measured (1μ amp. with shunt G) is $7\mu w/cm^2$ (about 34 m.c.). The sea photometer, which is always compared with the deck photometer before and after every series of measurements, has almost exactly the same emission.

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* Since the spectral sensitivity of the Photox cell corresponds closely to that of the human eye, the standardization of this photometer in meter candles does not involve as great an error as in other parts of the spectrum, reference 12.

In using the Photox photometer for measuring the reflection from the ocean, the light deck case was attached to the end of a long bamboo pole, and held some 4.5 m out over the side of the boat. The pole was turned so that the window of the photometer was directed first up and then down. Alternate measurements were made of I and $R+U$ as rapidly as possible, and in unsteady conditions the average of six or more alternate readings taken. Tests showed that slight deviation of the photometer from the horizontal, either in the upright or the inverted position, resulted in negligible variations in the response of the instrument provided that the altitude of the sun was not less than 20°. The value of $R+U$ did not change significantly with changes in the vertical distance of the photometer above the water from the highest accessible position of 3.5 m down to 1 m under conditions of smooth or slight sea.

In the use of the submarine photometer the accuracy of such measurements as could be made just under the surface was greatly enhanced by marking the cable supporting the instrument at measured small intervals with white lead. An observer was stationed to watch the cable and readings were taken only at those moments when as a result of the motion of the boat and the water a designated mark on the cable coincided with the surface.

OBSERVATIONS

The measurements of the total upward light, or $R+U$, made with the red and violet sensitive photometers on the floating photometric tower (Table I) show that only a slight difference exists in the values for these two components of day-

TABLE I. *Values of the total light coming upward from the surface of the water* ($R+U$) *as a percentage of incident light* (I). Measurements made with the violet and the red sensitive photoelectric photometers on the floating photometric tower.

DATE 1935	WIND—WAVE	SKY	TIME (Local apparent time)	ALTITUDE OF SUN	$R+U$ AS PERCENTAGE OF I Violet	Red
July 3 Buzzards Bay	SW Force 3	Clear	1233	70°	4.2%	2.5%
	Height of waves about 0.3 to 0.6 m	Clear	1338	62	4.1	2.4
		Clear	1433	53	4.3	2.5
	Same	Clear	1448	50	4.6	2.6
	Same	Clear	1518	44	4.8	2.9
	Same	Clear	1548	39	5.1	3.6
July 10 Buzzards Bay	Slight ripple	Many clouds, sun out	1123	69	11.2	
	No wind	Overcast	1218–1428	70–53	6.4 (Average)	
	Oily, no wind	Many clouds, bright sun	1458	47	5.9	
	Smooth	Full sun	1518	44	5.7	
	Light air	Full sun, many clouds	1600	36	6.8	
	Light breeze	Full sun, few clouds	1633	30	6.5	
	Light breeze	Full sun, few clouds	1708	23	8.4	
	Light breeze	Almost full sun, few clouds	1733	18	7.6	
	Light wind	Overcast	1748	16	6.7	
	Light wind	Sun through clouds	1808	12	6.7	
	Light wind	Overcast	1833–1903	8–0	6.5 (Average)	
July 23 Buzzards Bay	SW Force 3	Hazy sun	1118	68	9.3	5.7
	Waves 0.5 m	Slightly hazy sun	1203	68	7.7	3.6
	Waves 0.5 m	Clear	1243	65	6.4	5.6
	Waves 0.5 m	Clear	1318	62	5.8	6.3
	Waves 0.6 m	Clear	1345	56	6.2	7.0
	Waves 0.6 m	Many clouds	1433	49	8.4	9.9
	Waves 0.6 m	Many clouds, sun in and out	1508	42	8.2	10.7
August 8 Vineyard Sound	NW Force 3–4	Clear	1048	61	3.8	3.4
	NW Force 3–4	Clear	1123	64	3.9	3.4
August 8 Buzzards Bay	NW Force 3–4	Clear	1508	41	6.4	5.0
	NW Force 3–4	Clear	1538	36	7.3	5.3
	NW Force 3–4	Cloud over sun	1543	35		4.3
	NW Force 3–4	Clear	1613	29	9.1	7.0
	NW Force 3–4	Clear	1648	23	12.0	10.3
	NW Force 3–4	Clear	1718	17	14.2	20.5
	NW Force 3–4	Clear	1748	12	15.4	19.0
	NW Force 3–4	Clear	1823	5	12.7	35.2

light. $R+U$ for red light is almost always somewhat lower than for violet, as would be expected from the fact that the index of refraction for water is a little higher for the latter than for the former part of the spectrum. The green component was investigated exclusively with the Photox photometer except for one occasion when measurements were made with the green sensitive photoelectric photometer to compare the two methods. The instruments agreed to well within the experimental error and showed that the value of $R+U$ for green light is intermediate between red and violet.

$R+U$ reaches a minimum (about 4 percent for violet and 3 percent for red) on clear days when the sun is nearest the zenith; on cloudy days the value may reach 6 or 7 percent. After the sun has fallen below about 44° from the horizon the value of $R+U$ begins to rise. Below 30° on a clear day $R+U$ becomes steadily higher, and is higher then than under any other conditions. From 12° on the inaccuracy introduced by the unavoidable tilting of the photometers invalidates the measurements but there is every indication that $R+U$ becomes very high as predicted by theory. For solar altitudes of 12° to 30° $R+U$ ranged between 6 and 20 percent in clear weather. Whitecaps were found to increase $R+U$ only slightly, apparently because the foam produced covers a relatively small proportion of the total surface. This is in agreement with a value of 12 percent obtained over the foamy part of the boat's wake. Although the magnitude of the upward light has been found to remain an inconsiderable fraction of the incident light under all conditions, it must be remembered that its percentage may be two or more times greater on one occasion than on another and its absolute value varies with the strength of daylight.

Since these results point to a much lower value for the loss of light at the surface than was indicated by previous measurements of submarine illumination, an attempt was next made to measure with more care and precision than before the intensity of the light just below the surface. The Photox photometers were used for this purpose. Because of the high damping of the microammeter needle the deflection for a rapidly varying light gives a much steadier reading than with the potentiometer method, and the results are therefore much more reliable. All submarine measurements have been multiplied by the factor 1.09 to correct for "external internal reflection."[10]

Under conditions of absolute calm, clear sky, and glassy smooth water in Buzzards Bay it was possible to make measurements up to within 10 cm of the surface where 97.5 percent of the light was transmitted (Series 401, Fig. 3). The trend of the curve is straight from this point to a depth of 2.7 meters. When the curve is extrapolated to zero depth a value of about 100 percent is reached. The theoretical reflection (not including U) for the existing solar altitude of 40°, as calculated from Fresnel's law of reflection for a smooth water surface, is about 2.5 percent. The "surface loss" indicated by extrapolating a series of measurements which extend nearly to the surface should be compared with the true reflection R and not with $R+U$ because U is a "loss" only as far as the deeper strata are concerned. Accordingly, the agreement of these measurements with theory is good, as is the case also with the succeeding series of observations. A short time later when the sun was about 35° from the horizon and the theoretical reflecting power was about 5 percent, an actual measurement of $R+U$ gave 8.4 percent. In this case therefore U amounted to about 3.4 percent or almost half of the total upward light.

The situation is entirely different when the surface of the sea is disturbed as is revealed by a comparison with Series 325 made at the same place the year before[11] on a day when small waves existed. If the curve is extrapolated

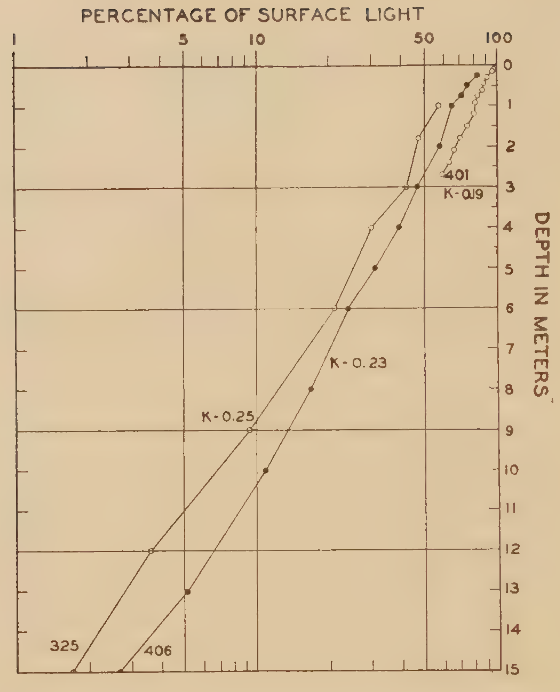

FIG. 3. Relation between depth and irradiation expressed as a percentage of the light just over the surface (logarithmic scale). Series number indicated at end of each curve. Series 325: Buzzards Bay, Aug. 28, 1934. 0926–1011 L.A.T. Av. altitude of sun 47°. Slight sea, few clouds. Green sensitive photoelectric photometer. Series 401: Buzzards Bay, Aug. 15, 1935. 1508–1538 L.A.T. Sun 40°. Glassy smooth sea, clear sky. Green sensitive Photox photometer. Series 406: Provincetown Harbor, Aug. 24, 1935. 1300–1335 L.A.T. Sun 54°. Slight sea, clear sky. Photox photometer.

beyond the 1 meter level, a "surface loss" of about 30 percent is indicated. Since the value of the transmissive exponent for the upper 6 meters ($k = 0.19$) is identical with that for Series 401, the difference in the position of the two curves cannot be due to a difference in the transparency of the water on the two occasions. Furthermore, we know from our present investigation that $R + U$ could not have been as great as 30 percent. It was therefore suspected that the stratum of water less than 1 meter thick just beneath the surface became relatively opaque when the surface of the sea was rough and that this condition disappeared in calm weather.

Such a situation was actually detected in measurements made in Provincetown Harbor (Series 406) on a clear day with wind force 4 (Beaufort Scale), small waves, and occasional flecks of foam. If the curve is extrapolated to zero depth using only points below 1 meter it indicates a surface loss of 15 percent or more. But when one extrapolates from points above 0.5 meter a loss of only 6 percent is found. In this case $R+U$ was 4.6 percent and U, measured directly by inverting the sea photometer and lowering it a few centimeters beneath the surface, was 3 percent. The abrupt change of slope in the curve reveals the increased rate of absorption and scattering within the first meter of water.

On Georges Bank (Station 2473) the roughness of the sea caused a regular heave of the sea photometer of 3 meters and prevented measurements from being made above 2 meters. The wind was force 3 and there were a few whitecaps. The curves for both the violet component (Series 410) and the green component (Series 408) of daylight extrapolate to 84 percent at the surface (Fig. 4). The value of $R+U$ was 5.5 percent, and of U measured 1 meter down was 2 percent.

South of Cape Cod (Station 2474) in smoother water with waves about 1 meter high, a wind of force 4–5, and numerous whitecaps, it was possible by watching the cable very carefully to make a measurement at 0.5 meter (Series 412, Fig. 4). Without this point the surface loss appears to be 14 percent, while with it the loss is reduced to almost nothing. $R+U$ was 4.6 percent.

The upward component of light beneath the surface was measured with an inverted photometer at each meter to a depth of 14 m in Provincetown Harbor where the depth is about 16 m. At 0.5 m the upward component was found to

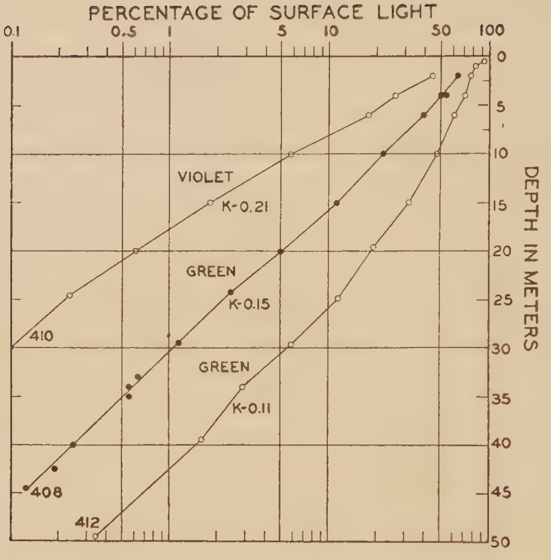

FIG. 4. Observations made on Georges Bank (Station 2473: Lat. 41° 51′, Long. 68° 44′). Aug. 25, 1935. Series 408: 1150–1250 L.A.T. Sun 59°. Moderate sea, many clouds. Photox photometer. Series 410: 1350–1450 L.A.T. Sun 47°. Moderate sea, overcast. Violet sensitive photoelectric photometer. Observations made south of Cape Cod (Station 2474: Lat. 40° 48′, Long. 71° 00′). Aug. 26, 1935. Series 412: 1214–1259 L.A.T. Sun 59°. Moderate sea, clear sky. Photox photometer.

be 4 percent of the downward component and this ratio increased gradually to a value of 6 percent at 14 meters. In Buzzards Bay the ratio was found by Dr. Oster the year before to be 4.8 percent at 1 m, 5.8 percent at 5 m, and 8.9 percent at 10 m. In the deep basin of the Gulf of Main (Station 2472: Lat. 41° 53′, Long. 69° 25′) we found a ratio of 2.5 percent at 0.5 m and this value remained unchanged to a depth of 20 m.

A few approximate measurements of the horizontal component of the submarine illumination were made by suspending the sea photometer by one end so that the receiving surface was vertical.[8] The photometer was caused to rotate slowly around a vertical axis in order that the window might face successively in all directions relative to the direction of the sun which was unobscured. A maximum and minimum intensity was thus recorded for each depth. In Provincetown Harbor the ratio of the maximum value for horizontal illumination at 1.5 m to the vertical downward illumination at the same depth was 16 percent and the ratio of the minimum horizontal illumination to the vertical illumination was 3.4 percent. At 10 m these ratios had increased to 17 percent and 7 percent, respectively. In the deep basin of the Gulf of Maine the ratios were 6 percent and 3 percent at 2 m, and 20 and 3 percent at 15 m. From these rough measurements and those of the vertical upward light, it is seen that the illumination becomes more and more diffuse with increasing depth but the directional character of the light is lost only slowly.

Conclusion

From the foregoing observations we may conclude that the discrepancies which have been termed "surface losses" do in fact exist but that they are not due chiefly to a "loss" at the very surface. They are due, however, to a stratum of relatively opaque water which exists just beneath the surface and which has generally escaped notice because of the difficulty of making precise measurements at shallow depths. The only portions of the incident light which are "lost" are the component which is reflected from the surface R and the component which escapes upward from the water U and our measurements have shown that the magnitudes of these components are relatively small.

The average value of all our measurements of $R+U$ for solar altitudes greater than 30° is about $6\frac{1}{2}$ percent for cloudy days and about 4 percent for clear days. Differences in the condition of the sea surface ranging from flat calm to waves with whitecaps has very little effect on these figures. The value of $R+U$ was not more than a few units higher in the more opaque inshore waters than in the clearer water of the Gulf of Maine. $R+U$ is never more than 9 percent except when the sun's altitude is less than 30° with a clear sky. These conditions would exist during only a small portion of the day for most of the ocean, but the greater reflection losses at lower solar altitudes is undoubtedly of considerable importance in polar seas. For values of $R+U$ of 9 percent or less, R and U were found to be about equal in magnitude. Therefore, the portion of daylight which never enters the water at all, namely R, is never more than a few percent of the incident light and consequently of negligible importance.

These results form an interesting comparison with the measurements of Kimball and Hand[20] of the reflectivity of different kinds of surfaces made from an aeroplane in the vicinity of Washington, D. C. near noon on three days in January, February, and May. These investigators flew over bare ground, fields, forests, rivers, and Chesapeake Bay mostly at altitudes greater than 1000 ft., and recorded simultaneously the light from an overcast sky and from the terrain below. In no case was the reflection found to be greater than 11 percent except where considerable snow existed. A maximum value of 89 percent was recorded over a very white snow field. Green fields and bare ground reflected 6 to 10 percent, dark forests about 4 percent, and light forests about 9 percent of the incident light. Values of 5 to 10 percent were obtained over the Potomac River (at altitude of 10–20 ft.) and of about 6 percent over the Patuxent River. The reflection from Chesapeake Bay on the January trip when the surface was smooth was 9.7 percent (altitude 2000 ft.), but in May, when whitecaps existed, the values obtained varied from 3.4 to 4.9 percent (altitude 2000–3000 ft.). No significant difference was found between the measurements near shore and those made more than $1\frac{1}{2}$ miles out where conditions approximating the ocean were believed to exist. It is extremely satisfactory that these observations agree so closely with ours which were made only a few feet above the surface. They also agree with the reflection from a grass lawn measured in the quadrangle of the Biological Laboratories, Cambridge, at 1.30 P.M. E.S.T., Nov. 4, 1935, where we obtained 10 percent reflection in the sun and 9 percent in the shade with the Photox deck photometer.

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[20] H. H. Kimball and I. F. Hand, Monthly Weather Review, U. S. Weather Bureau **58**, 280 (1930).

Under conditions of absolute calm the transparency of the water remains unchanged up to within at least 10 cm of the surface. The "surface loss" deduced from extrapolation is very small and in agreement with the low magnitude of the reflection. But as the sea's surface becomes more and more disturbed, the "surface loss" discrepancy becomes larger and larger. Its magnitude is usually about 15 percent[5, 8] but has often been reported as much greater. Since we have found that the value of $R+U$ does not become significantly larger under rough conditions than in calm weather, it follows that the amount of light absorbed in the upper meter or so has greatly increased. Careful investigation of this stratum has proved that this is indeed the case. The abrupt changes in slope near the surface in our transparency curves which prove this fact are also to be seen in the curves of other investigators in those few cases where measurements have been made at depths of less than one meter.[10]

The cause of this diminished transparency of the surface layer is undoubtedly the presence of bubbles produced by a disturbance of the water. Chemical substances, particles of sediment, and planktonic organisms are uniformly distributed over a much greater depth than the thickness of this anomalous stratum by the vertical mixing produced by turbulence. In every case where a large "surface loss" has been recorded either white caps or a tide rip has existed. In calm weather the phenomenon disappears. From any high point on a boat the presence of clouds of bubbles below the surface may be observed which are produced by whitecaps and remain under water long after the disturbance has passed. These bubbles reduce the light by scattering and multiple reflection.

SUMMARY

(1) Measurements were undertaken to ascertain the cause of the large "surface losses" which have been found in the investigation of submarine illumination and to determine the influence of different conditions of sky and sea on the magnitude of such losses.

(2) The light "lost" from the ocean may be expressed by $R+U$ in the equation $I=A+R+U$ (where I=incident light, A=light absorbed by the water, R=light reflected from the surface, and U=light which enters the water but is reflected out again). The value of $R+U$ was investigated by securing photoelectric photometers in an inverted position at the top of a floating tower. The photoelectric current was measured with an integrating device employing a Thyratron tube and relay.

(3) A new sea photometer and a new deck photometer were constructed by using the Westinghouse Photox Cell (rectifier type) and a highly damped microammeter. These instruments were carefully tested and standardized and found extremely satisfactory for the measurement not only of reflection but also of the illumination just beneath the surface.

(4) The value of $R+U$ in Buzzards Bay reaches a minimum of about 3 to 4 percent on clear days when the sun is nearest the zenith. The percentage is increased by one or two units when waves exist and by a few units more when the sky is cloudy, and is decreased by a few units in clearer off shore waters. $R+U$ is never more than 9 percent for solar altitudes

greater than 30° in clear weather. *R* and *U* are about equal in magnitude.

(5) The greater part of the "surface loss" was found to be accounted for by a stratum of relatively opaque water extending to a depth of about 1 meter and caused by bubbles in this stratum the abundance of which is proportional to the roughness of the sea surface.

Contribution No. 99

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BIOLOGICAL OBSERVATIONS ON THE MARINE FUNGI OF WOODS HOLE WATERS

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Introduction

While the rôle played by marine bacteria in the decomposition of organic complexes is appreciated by all interested in a study of the ocean, the activities of fungi in this respect are practically unknown. Indeed, it may be justly said that the very existence of fungi which complete their whole life history in the sea is not known to most students of marine biology.

Occasional references to these rare and peculiar organisms may be found in the European literature from the 1860's onward. In the accounts of the early students of the seaweeds certain structures generally supposed by them to be the reproductive organs of the algæ were described and figured, which in many cases have been found to be, in reality, extraneous, parasitic fungi. In fact, practically all of the few marine fungi thus far found have been described as parasites or saprophytes of various marine algæ.

Representatives of four groups of the fungi have been discovered in marine waters, namely, the Myxomycetes (Labyrinthuleæ), Phycomycetes, Ascomycetes, and Fungi Imperfecti. Of the alga-inhabiting species which are truly parasitic or hemi-parasitic, those of the Phycomycetes seem to predominate. Many of these are not only able to initiate the infection of a healthy host, but once the alga has been killed have the capacity to live saprophytically on the dead contents, often in company with bacteria and Protozoa which have entered as secondary agents of destruction.

Only two papers have thus far appeared which deal at all extensively with marine fungi (Petersen, 1905; Sparrow, 1934) and both of these are concerned with forms collected in northern Europe. Twenty-three different organisms are described in these papers, all but one of which (*Pythium marinum* Sparrow) are ordinarily included in the order Chytridiales of the Phycomycetes. In our own waters two undoubted Phycomycetes have thus far been reported from the Pacific coast

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[1] Contribution No. 99.

(Zeller, 1918), while the Atlantic side has apparently yielded but a single one (Martin, 1922). Recently, Papenfuss (1935) has mentioned a chytridiaceous parasite of the brown alga *Ectocarpus siliculosus* Dillw. which he states attacked about 50 per cent of the unilocular sporangia, but he does not name the organism. This material was collected in the vicinity of Woods Hole, Mass.

The present investigation was initiated with two points in mind: first, to determine whether or not marine Phycomycetes were actually present in Atlantic coastal waters—a point not altogether evident from the extant literature—and secondly, to determine, if such were found, the nature and extent of their activities in the cycle of decomposition of marine organic complexes. This paper embodies the results of the work done mainly during the summer of 1934, and, to a lesser extent, a portion of the summer of 1935 on the first of these objectives and includes not only an enumeration of the fungi found in the vicinity of Woods Hole, Mass., but in addition, pertinent notes on their morphology, life history, and taxonomy.

Fungi Collected

1. *Labyrinthula sp.* Saprophytic in cells of *Rhizosolenia spp.,* bottom of Great Harbor, August 14, 1934.

In debris dredged from the bottom of Great Harbor during a heavy "flowering period" of diatoms, large numbers of *Rhizosolenia spp.* were found in various stages of decomposition. In these cells there were often found the motile stage of a *Labyrinthula* (Text Fig. 35), sometimes in company with a Protomyxa-like protozoan, or a small chytrid. The fusiform swarm cells of the *Labyrinthula,* which were 12 μ long by 5 μ in diameter, made their way in and upon the algal cells by gliding along their tenuous pseudopodia. The most anterior of these cells, which was not preceded by any protoplasmic attenuation, displayed remarkable powers of amœboid movement. No solid particles could be detected within the swarm cells.

The uncertain taxonomic status of the species of this peculiar group does not allow of any specific designation of the present form. Morphologically it does not seem very different from *Labyrinthula macrocystis* described from marine algæ by Cienkowsky (1867), from the common inhabitant of diseased *Zostera* (Renn, 1934), nor, indeed, from certain fresh-water forms.

Very frequently in the debris which collects in the bottom of aquaria containing marine algæ, species of *Labyrinthula* are observed, and it is probable that they occur much more frequently than records in the literature indicate—a fact also evident from Miss Jepps's (1931) paper.

No cases of actual parasitism of algæ by these forms were observed, and at Woods Hole, at least, the organism on *Rhizosolenium* appears to lead a saprophytic existence. Experiments to test the pathogenicity of various strains of *Labyrinthula* are greatly needed.

2. ?*Labyrinthula Chattoni* Dangeard. Parasitic(?) in *Cladophora sp.*, vicinity of Woods Hole, throughout the summer.

Very commonly in material of *Cladophora* which has been maintained in the laboratory for some time there will be found occasional greyish cells within which are rosettes of highly refractive material, generally surrounding a central mass of compacted brown granules—the remains of the host chloroplasts. These rosettes are divided radially into a varying number of segments from which at maturity numerous very minute amœboid bodies emerge. According to Dangeard (1932), these are the motile spores of the fungus, and he has figured numbers of spindle-shaped bodies which unite to form a net-plasmodium. In the present material no fusiform shape was ever assumed by the spores, although the bodies from which they emerged—considered by Dangeard to be sori—resembled closely those of his species; neither was a net-plasmodium formed, and for these reasons the writer considers a further study of the Woods Hole fungus necessary before definitely naming it.

3. *Protomyxa*-like parasite of *Bryopsis*. Parasitic in *Bryopsis plumosa,* vicinity of Woods Hole, summer of 1934, June, 1935; New Bedford Harbor, Mass., July 24, 1934.

In the course of studies made on a fungous parasite of *Bryopsis* (*Sirolpidium*) there was frequently found an exceedingly virulent parasite which is undoubtedly a protozoan. However, since the animal occurred in such abundance and very often in competition with the fungus, both usually consuming the entire contents of infected cells, it would seem of interest to include it here.

Infected cells were readily noted by their blackened appearance, a pathological symptom also produced by the fungus. The method of entrance of the parasite and the nature of the unit accomplishing this were not determined. Once established, the organism gradually enveloped part or all of the algal content which soon became discolored within its body. The shape of the invader was variable but in general resembled a giant amœba from any part of the surface of which delicate, often strongly contractile threads emerged. Very marked movement of these threads could be detected and frequently broadly fusiform or spherical enlargements containing algal material could be seen moving along them

(Plate I, Fig. 6) in much the same "trolly-wire" fashion as that observed in *Labyrinthula.*

In exhausted algal cells the animal seemed to go into a resting stage and to surround itself with a slightly thickened, rigid pellicle. The engulfed host contents were by now nearly black, and it was these cylindrical bodies with rounded ends which were so evident macroscopically.

A similar organism has been found very frequently in decaying *Rhizosolenia spp.* dredged from the bottom of Great Harbor and in dead cells of *Ectocarpus* from Gay Head.

4. *Ectrogella perforans* H. E. Petersen. Parasitic in *Licmophora abbreviata,* summer of 1934, June, 1935; *Striatella unipunctata,* summer of 1934, June, 1935; vicinity of Woods Hole; New Bedford harbor, July 24, 1934; Gay Head, Martha's Vineyard, Mass., July 16, 1934.

This virulent parasite is the commonest marine fungus in the vicinity of Woods Hole and during the summer it is almost impossible to find stands of *Licmophora* and *Striatella* not heavily infected with it. It not only occurs in all the littoral regions in the immediate vicinity of Woods Hole but has also been found in equal abundance in New Bedford Harbor and Gay Head. It is probable that it will be found along our coasts wherever the host plants grow. During the month of July in particular the fungus may occur in epidemic proportions (Plate III, Fig. 2). As many as 88 per cent of the diatoms (*Licmophora*) in a single mount containing many hundreds have been observed to be infected.

Since the present form presents no significant differences in morphological features from that recently described by the writer (1934) from Danish material found in the littoral of the Kattegat, it will not be dealt with in detail here, save for certain hitherto unknown phases.

In both *Licmophora* and *Striatella* there was ordinarily present in one infected diatom only a single, spherical, highly refractive thallus, although occasionally 2–5 were observed. This varied from 25–35 μ in diameter and lay loosely in the center of the host cell.

A good opportunity was afforded in several instances to determine the method of entrance of the parasite into the host cell, a feature not previously observed. Heavily infected colonies of diatoms contained many cells, to the outer surfaces of which adhered numerous minute (3 μ in diameter) quiescent cystopores of the fungus. The small size of these bodies made observations difficult, but in several cases spores were found from each of which a tenuous, needle-like penetration tube had emerged and had pierced the host wall. It is probable that, like other parasitic chytrids, the contents of the spore then flowed through the tube into the algal cell, leaving the wall of the cyst outside. Such empty cystospores were found, although the actual passage of material into the cell was not witnessed. Once inside, the refractive fungous protoplasm soon assumed a central position in the host cell, possibly attaching itself to the nucleus of the diatom. Growth into the mature, somewhat spherical sporangium then ensued. The star-like arrangement of the chloroplasts of the host was soon destroyed and, as the fungus developed, their individual structure was broken down and their normal color lost. At no time was any host material observed to be ingested directly nor did the fungus exhibit any signs of amœboid motion. As the *Ectrogella* increased in size, the disintegrating host material usually became collected around the periphery of the parasite, where it gradually became reduced to a small amount of granular, chestnut-brown residue. The nature of this unassimilated material is not known.

There then took place a transformation of the contents of the thallus into innumerable, minute zoöspores. These were discharged through 1–5 stout tubes into the water. A point of great morphological and taxonomic interest was determined from the spores of this material. Petersen (1905) states that in this species they are anteriorly uniciliate, the cilium being directed posteriorly when the spore is in motion. In the Danish material previously observed, the writer (1934) was unable to determine the ciliation, but at Woods Hole, the spores were found to be biciliate. This finding was confirmed in many instances. The body of the zoöspore is pyriform, somewhat curved, and at the narrower, forwardly directed end there is usually a refractive droplet. The two, perhaps anteriorly attached, cilia are directed oppositely when the spore is in motion. The relative lengths of these two structures could not be determined. Motion through the water was of an uneven, twisting character. The resemblance of these spores to those of *Sirolpidium* (Sparrow, 1934) is very marked.

From these observations, the parasite can now with real reason be placed in the genus *Ectrogella* as amended by Scherffel (1925).

At no time during the process of disintegration of the host cell could the presence of any other type of organism be detected. Bacteriological stains were employed to determine whether or not bacteria assisted in the process of disintegration, but none was ever observed. Indeed, the fungus had apparently so completely absorbed the available nutriment that even after infected cells had become broken or had fallen apart, bacteria and Protozoa were seldom seen feeding on the residual material.

It was very evident that not only could the fungus initiate the infection, but once inside, could bring about, unaided by other agencies, the almost complete disintegration of the contents. Further, the thallus, derived from a single zoöspore, at maturity became transformed into a myriad of swimming spores, each of which was potentially able to infect another diatom. Hence, in a region with an abundance of favorable host material, the rapid and widespread dissemination of the parasite could be quickly accomplished.[2] Indeed, it is remarkable in view of the high percentage of infection observed, that the two species of diatoms were able to maintain themselves at all. It is hoped that a more comprehensive study of this disease can be made in the future.

5. *Eurychasmidium tumefaciens* (Magnus) n. gen. Parasitic in the nodal cells of *Ceramium diaphanum*, Sheep Pen Cove, Woods Hole, August 27, 1934, collected by C. Jao; Little Harbor, Woods Hole, August 29, 1934, collected by the author.

Eurychasmidium n. gen. Plasmodial thallus entirely intramatrical, one-celled, filling the distended host cell, forming at maturity many discharge tubes which pierce the host wall; zoöspores biciliate, encysting near the sporangium after discharge, ultimately emerging as motile zoöspores. Resting spores not observed.

Thallus plasmodialis, omnino intramatricalis, unicellulatus, cellulam matricis distentam implens, maturitate formans multa ostiolata perforantia parietem cellulæ matricis; zoosporæ biciliatæ, encystantes extra sporangium post emissionem, e cystis emergents velut sporæ motiles. Sporæ perdurantes non observatæ.

Eurychasmidium tumefaciens (Magnus) comb. nov.
Syn. *Chytridium tumefaciens* Magnus.
Olpidium tumefaciens (Magnus) Berl. et de Toni.

Thallus filling the host cell; spherical or irregular and lobed; producing a marked enlargement of the host cell and stimulating the host to form clusters of lateral branches; becoming transformed into a single sporangium, the spherical ones 100–110 μ in diameter, the lobed examples up to 110 × 200 μ long. Zoöspores formed within the sporangium (ciliated?), upon discharge through as many as 30 discharge tubes forming a dense motionless cluster near the sporangium; encysting, the somewhat loosely disposed cysts being angular and 4 μ in greatest width; emerging from the cysts after a period of quiescence as ellipsoid, biciliated spores, 3 μ in diameter by 5 μ in length. Resting spores not observed.

This remarkable fungus which usually attacked only the nodal cells of the *Ceramium* possesses many points of interest. In its method of infection, developmental features, and effect on the host cell it resembles to a marked degree *Eurychasma Dicksonii* (Sparrow, 1934). However, it differs from this genus since it always remains intramatrical, since the zoöspores undergo a period of encystment outside the sporangium, not inside, as in *Eurychasma,* and since it produces adventitious lateral branches and a more marked swelling of the host cell (Plate I, Fig. 1).

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[2] One curious evidence of the virulence of this fungus was noted. In a mount containing many swimming spores, a species of *Vorticella* was observed which had captured 10 or more zoöspores. The latter instead of being digested by the animal, had reversed the process and had absorbed the contents of the protozoan and were forming sporangia!

The earliest stages observed in the development (Text Figs. 14, 15) showed an already well-established thallus easily distinguishable in the distended host cell by the presence of numerous irregular, refractive bodies. As growth proceeded, the disintegrated chloroplast material became more granular while the host protoplasm assumed a vacuolate character (Text Fig. 18). Coincident with the increase in size of the fungus there was a strong distention of the host cell (Text Fig. 17).

Infection is unquestionably initiated by the zoöspore, probably in the same manner as described for *Ectrogella perforans.* While actual observations on this point were lacking, there were occasionally observed instances similar to Text Fig. 16, in which the empty cyst and remains of the penetration tube were still present on the infected cell. The sequence of changes ensuing in the fungous protoplasm itself as growth proceeded were entirely similar to those described by Petersen (1905) for *Eurychasma,* including the characteristic "stade écumeux" (Text Fig. 19).

During enlargement of the host cell, a pronounced thickening of the algal wall material was noted. Also, certain adjacent nodal cells were stimulated to divide and there was produced in the vicinity of an infected cell a number of curved, stunted, lateral branches which gave a "bushy" appearance to the region (Plate I, Fig. 1). Such places could easily be detected with a hand-lens. Since the fungus was not observed to form any rhizoidal system, but was confined to a single cell, it would seem that some sort of substance was produced in infected cells which diffused to adjacent ones and stimulated them to abnormal growth.

Occasionally, infected apical cells of *Ceramium* were found with 2–6 thalli in them, probably the result of multiple infection. If these were produced by the same fungus as found in the nodal cells, it is interesting to note that here, very little hypertrophy occurred.

Unfortunately, the final stages in the formation of the zoöspores and their discharge from the sporangium through many discharge tubes were not observed, in most cases evacuation of the spores having taken place before the preparations were made. Nor could means be found to promote maturation and discharge of sporangia under observation. Hence, it is not known whether the spores emerge by ciliary action or are forced out of the sporangium. Once emerged, however, they form a dense cloud around the infected filament, each spore being surrounded by an angular wall (Text Fig. 21). These cystospores are not connected with one another as they appear to be in the sporangium of *Eurychasma* but are loosely disposed in the medium (Text Fig. 20). After an unknown period of quiescence the protoplasm of each of these cysts emerges, probably through a pore formed in the wall, and undergoes near the empty shell a rocking and fashioning which terminates with the production of the fully formed spore. The body of the spore is somewhat elliptical, generally possessing a single, minute refractive droplet, and two cilia—the latter point being determined from a study of killed and stained material. Further observations on the orientation, length, and points of attachment of these cilia are needed.

This fungus is a true parasite, initiating and carrying to completion the destruction of the host cell unaided by other agencies. Unlike certain other marine fungi, however, it does not seem able to continue its destruction of the alga after the latter has been noticeably weakened, as, for example, by remaining under laboratory conditions for a time. The remainder of the host plant, save in the immediate vicinity of an infected cell appears unaffected by the incursion of the fungus.

6. ?*Petersenia sp.* Saprophytic in *Ceramium diaphanum,* Little Harbor, Woods Hole, August 29, 1934.

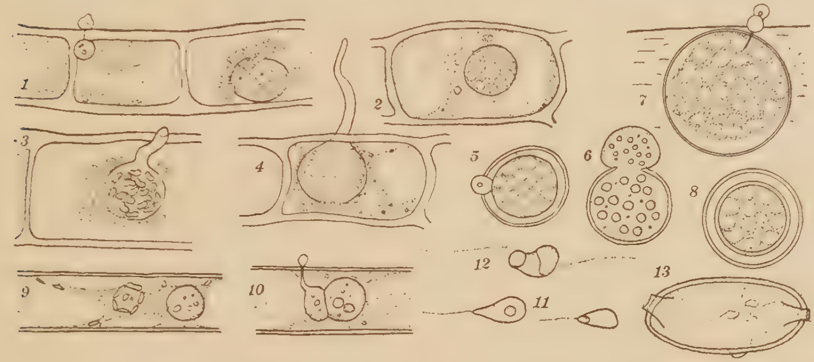
In material of *Ceramium diaphanum* which had been kept in the laboratory in an aquarium for several weeks, there was found a " Pleotrachelus "-like fungus, probably to be regarded as a saprophyte in the alga. In contrast to the previously described fungus on this alga, the present form was found only in the internodal cells and in further distinction was never observed to produce any hypertrophy of the host.

One to many thalli of varying size (20–96 μ in diameter) were formed in a single internode (Plate II, Fig. 4). While maintaining in general a spherical shape, these thalli occasionally assumed irregular forms, though no lobed examples were found.

The mature sporangium was characterized by its relatively large size, attaining frequently a diameter of 96 μ or more, although occasional specimens measured only 20–25 μ. At maturity up to ten or more narrow, distally tapering, radiating discharge tubes (about 7 μ in diameter) were formed (Plate II, Fig. 3) which bored through the cell wall of the alga. Zoöspores and resting spores were not observed, and hence the exact generic disposition of the fungus awaits the results of further investigations. If, as is probable, the swarmers are found to be biciliate, affinity with *Olpidiopsis* and more especially *Petersenia* would be indicated.

7. *?Petersenia sp.* Parasitic in eggs of a microscopic animal (rotifer?), Sheep Pen Cove, Woods Hole, August, 27, 1934.

Adherent to filaments of *Ceramium diaphanum* there was an abundance of eggs of a microscopic animal, probably belonging to the *Rotiferæ,* members of which were swarming in the mount. Some of these were parasitized by a fungus allied to *Petersenia* and *Olpidiopsis.* The thallus occupied the whole of the interior of the egg and at maturity was transformed into a single sporangium 50 μ long by 20 μ in diameter. This was provided with 1–3 broad (8 μ in diameter), short, discharge tubes (Text Fig. 13). The actual formation and discharge of the zoöspores was not witnessed, although a number of these bodies which had failed to emerge were observed within the sporangia. These were reniform, of the "laterally biciliate" type, 4 μ long by 2 μ in diameter, and were very similar to those formed by *Pythium.*



Text Figs. 1–13. Figs. 1–8, *Petersenia Andréei;* Fig. 1, early stage in the formation of the thallus in *Ectocarpus,* the collapsed cyst of the infecting zoöspore and the penetration tube still present, a more mature thallus is seen in the right-hand cell, × 376; Fig. 2, more mature thallus containing characteristic refractive bodies, × 376; Fig. 3, mature, unopened sporangium showing some of the zoöspores which are actively moving within it, × 376; Fig. 4, mature sporangium with long extramatrical discharge tube, × 376; Fig. 5, mature resting spore with male cyst adherent to it, × 600; Fig. 6, conjugation of thalli previous to resting spore formation, × 525; Fig. 7, immature resting spore with two cystospores, which have apparently conjugated, attached by a penetration tube to it, × 760; Fig. 8, mature resting spore showing interpretation of wall structure, × 600. Figs. 9–11, (?) *Olpidium sphacellarum;* Fig. 9, young, spherical thallus in hair of *Sphacelaria,* × 525; Fig. 10, young thallus attached to nucleus of host cell, the cyst of the infecting zoöspore and penetration tube still persistent, × 525; Fig. 11, interpretation of two zoöspores, free-hand. Fig. 12, *Petersenia Andréei,* interpretation of zoöspore, free-hand. Fig. 13, *Petersenia sp.* in egg of rotifer, discharged sporangium containing a few zoöspores, × 376.

No bacterial or other biological agencies appeared to assist in the destruction of the eggs. It is hoped that more material of this fungus can be found in order that a further study of its method of infection, as well as the formation and discharge of the zoöspores can be made. From the ciliation of the spores there seems little question of its relationship to *Petersenia*.

8. *Petersenia lobata* (Petersen) Sparrow. Parasitic on *Callithamnion roseum,* growing on *Chorda filum,* dredged from between East Chop and West Chop Lighthouses, Vineyard Haven, August 22, 1934; Sheep Pen Cove, Woods Hole, August 23, 1934.

This peculiar fungus was abundant in certain tufts of the host, but it was never observed to attack all the plants on a single *Chorda.* Cells near the base of the tuft were most frequently infected.

The predominating type of thallus found in this material was cylindrical with rounded ends, although there occurred numerous lobed examples, often of very bizarre appearance (Plate II, Figs. 1, 2).

A morphological and taxonomic discussion of this fungus has recently been given by the writer (1934) and since no unusual features were displayed by the American material, it will not be repeated here.

In the early stages of invasion of the host cell, the parasite is unassisted by other organisms. However, in old infections, an abundance of bacteria and Protozoa are always found and it seems probable that the fungus initiates the destruction of the host cells, being aided in later stages by these other agencies.

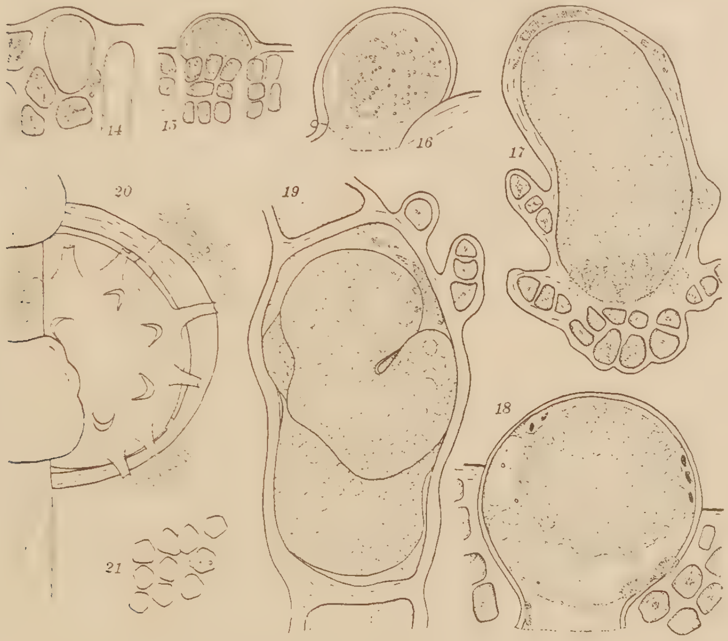
9. *Petersenia* (*Olpidiopsis*) *Andréei* (Lagerheim) comb. nov.
Syn. *Pleotrachelus Andréei* Lagerheim, 1899.
Pleotrachelus ectocarpi Jokl, 1916.

?Parasitic in *Ectocarpus siliculosus,* dredged off Gay Head, Vineyard Sound, July 16, 1934; Great Harbor, Woods Hole, August 24, 1934.

Frequent examples of extensive infection of host plants were found in the material from Gay Head, and quite commonly large fronds were observed with nearly every cell showing evidence of fungous activity. Such plants were easily recognized by their slightly greener appearance. So extensive was the infection that it could not be determined whether the fungus was the primary cause of the destruction of the alga, or whether it was only a saprophyte.

There was little doubt as to the method of entrance of the fungus. Numerous examples similar to Text Fig. 1 were observed which clearly showed that the zoöspore, after coming to rest on the surface of the host, had gained entrance by the formation of a penetration tube through which the content of the spore passed into the interior. It was the disorganized condition of the host cell contents even in early stages of infection which seemed to indicate that the fungus was probably only weakly parasitic or even saprophytic.

Further development involved the enlargement of the thallus (Text Fig. 2), accompanied by a gradual disintegration of the host contents. One to three thalli were usually formed in a single cell. The mature sporangia lay loosely in the host cell and were generally spherical and 18–20 μ in diameter (Text Fig. 4). A single discharge tube, 4–5 μ in diameter, was formed which often extended for as much as 78 μ out into the water. Occasionally, the tube did not achieve a correct orientation, in which case it passed through a number of host cells before reaching the outside.



Text Figs. 14–21. *Eurychasmidium tumefaciens.* Figs. 14, 15, early stages in the formation of the thallus in *Ceramium diaphanum*, × 225; Fig. 16, more mature thallus showing at the bottom of the left-hand side the remains of the infecting zoöspore and its penetration tube, × 376; Figs. 17–19, strongly hypertrophied host cells with vacuolate thalli of the fungus in them, Fig. 19 shows one of the infrequently formed lobed thalli, all × 225; Fig. 20, empty sporangium showing the many discharged tubes formed and a few of the encysted zoöspores, the latter formed a dense cloud around the sporangium, × 225; Fig. 21, cysts formed by the discharged zoöspores, from all but one of which the spore has emerged, × 760.

The zoöspores were fully formed within the sporangium by a process of progressive cleavage. After maturation, and before dissolution of the tip of the discharge tube, they underwent a prolonged period of violent individual movement and " milling around " (Text Fig. 3). Upon the opening of the discharge tube they escaped by their own efforts from the sporangium. In their morphology, these spores (Text Fig. 12) are strikingly like those of *Pontisma* (Sparrow, 1934), being irregularly piriform, arched, 5 μ long by 3 μ in diameter, and possessing at the narrow, forward end, as well as at the broader posterior one, a strongly refractive region. As has been suggested for *Pontisma,* a broad central, transverse groove and a " doubling-over " of the ends may account for this peculiar appearance. However, because of their small size, observations on moving spores are difficult. From the more anterior part of the groove there arise two cilia which appear to be of nearly equal length and are disposed in opposite directions along the long axis of the spore. These observations confirm Petersen's (1905) brief statement that the spores are laterally biciliate.

The spores moved in an erratic manner through the water. In hanging drop cells many of them germinated, each giving rise to a single, slender, very irregular tube, often of considerable length (30 μ).

Resting spores occurred in abundance (Plate I, Fig. 8). It will be recalled that in the Danish material of what is probably the same species, the writer (1934) showed that resting spore formation was apparently preceded by a conjugation between thalli of unequal size, the contents of the smaller passing into the larger which became the resting body. In the present fungus a similar phenomenon was observed in many instances and there seems little question that the resting spores are produced as a result of a sexual act almost identical with that found in the genus *Olpidiopsis.* Communication between the two cells was affected by the formation of a pore, no evidences of a definite fertilization tube ever being found. While, in general, the two conjugating thalli were more nearly equal (12 μ, 23 μ) (Text Fig. 6) than was observed in the Danish material (17 μ, 5 μ), occasionally they differed greatly in size (20 μ, 8 μ) (Text Fig. 5).

The mature resting spore was spherical, 20–23 μ in diameter, and appeared to be surrounded by a thick wall. However, under high magnification it was seen that this apparent wall could be resolved into the following structures: an outer, very definitely thickened membrane surrounding the whole, an inner membrane of the same thickness surrounding the refractive contents, and between them, a clear zone (Text Fig. 8). Whether the spore itself is to be regarded as relatively thin-walled and resting within a larger structure, or whether all of these parts are fused into a common surrounding layer, is not clear. Further observations on the development of the resting spore will be necessary to clarify this point.

Another puzzling feature was the absence in some cases of companion cells on the mature resting spores. Either the cyst was hidden from view by the body of the spore, or it soon disintegrated, or conjugation occurred in some other manner. Some evidence in favor of the latter case is given by the condition shown in Text Fig. 7. Here, attached to an immature resting spore by a tenuous penetration tube, are the cysts of two zoöspores which apparently have conjugated. It is entirely possible that after this process the merged plasma entered the host and there formed the resting spore.

In material of *Ectocarpus* in a floating *Chorda* complex collected in Great Harbor, Woods Hole, what appeared to be germinated resting spores were found. In the process of germination, the inner wall had apparently been absorbed, a long evacuation tube formed, and the contents, undoubtedly in the form of zoöspores, had been discharged through it.

EXPLANATION OF PLATE I

All photographs were made from living material with the exception of Plate I, Figs. 3, 5, and Plate II, Figs. 4, 5, which were made from material mounted in glycerine and stained with eosine. The approximate magnifications are given in each instance.

FIG. 1. *Eurychasmidium tumefaciens,* parasitic in *Ceramium diaphanum.* Two hypertrophied cells are shown; the right-hand filament has produced lateral branches in response to the incursion of the fungus. The indistinctness of the right-hand figure is due to the presence of a cloud of spores which has just been discharged from the sporangium. × 80.

FIG. 2. *Thraustochytrium proliferum,* saprophytic on *Bryopsis plumosa.* The right-hand figure is a sporangium with the spores about to be discharged; the highly refractive body at the base of the sporangium is the fundament of the new sporangium which will develop after discharge of the spores. The left-hand figure may possibly be an immature resting spore. × 380.

FIG. 3. (?)*Olpidium sphacellarum,* parasitic in *Sphacelaria cirrhosa.* An empty sporangium with two lateral, oppositely placed discharge tubes. × 330.

FIG. 4. *Sirolpidium bryopsidis,* in *Bryopsis plumosa.* Typical olpidioid thalli formed from the fragmentation of an originally filamentous thallus. × 380.

FIG. 5. *Pontisma lagenidioides,* saprophytic in *Ceramium diaphanum.* Habit of the segmented thallus in the alga. × 380.

FIG. 6. *Protomyxa*-like animal parasitic in *Bryopsis.* The delicate pseudopodium of the animal bearing a large spherical and two small, fusiform enlargements may be seen extending from the top to the bottom of the photograph. × 380.

FIG. 7. *Sirolpidium bryopsidis* in *Bryopsis.* Thalli after 24 hours exposure to dripping sea-water. Compare with Fig. 4, which is under completely submerged conditions. × 380.

FIG. 8. *Petersenia Andréei,* parasitic (?) in *Ectocarpus.* Resting spores in cells of filament. × 250.

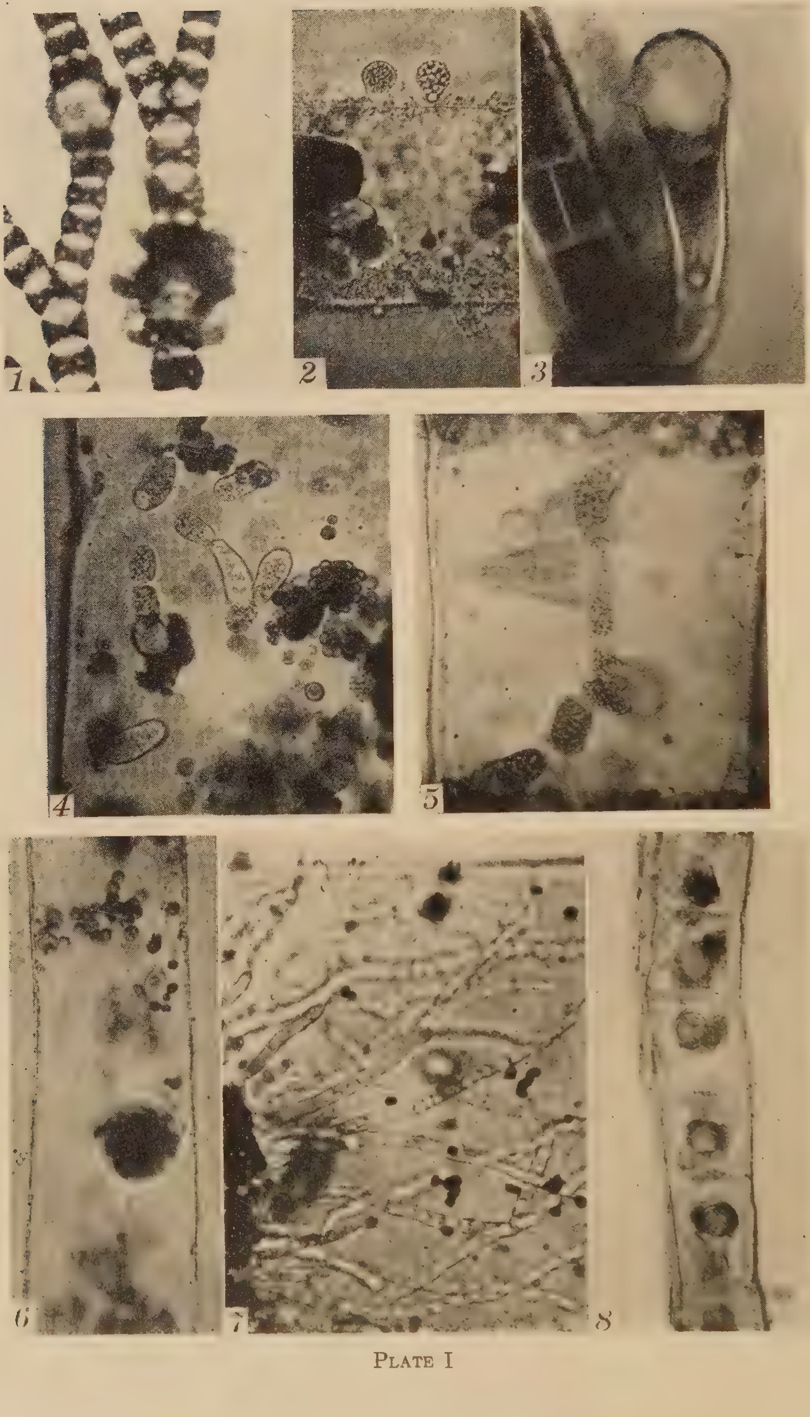


PLATE I

While a *Protomyxa*-like organism was abundant in certain cells of the *Ectocarpus,* the parts of the host occupied by the fungus were free from the animal, and, so far as could be determined, from other biological agents of disintegration as well.

10. (?) *Olpidium sphacellarum* Kny. Parasitic on *Sphacelaria cirrhosa,* Pine Island, Woods Hole, June 24, 1934.

This fungus was found in only one collection of the alga, although a search was made for it throughout the time the host was available. It attacks chiefly the apical cells of the lateral branches (sporangia?) and the colorless setæ. The rest of the plant appears immune and is not visibly affected by the presence of the fungus.

Early stages in the development were found, particularly in the colorless setæ. The infecting unit is the zoöspore, which comes to rest on the host, encysts, and produces a tenuous tube which penetrates the algal wall and through which the contents of the spore are conducted into the cell. In many cases the young thallus attaches itself to the nucleus of the host cell (Text Fig. 10). It then gradually enlarges into a spherical (Text Fig. 9), or often cylindrical structure with rounded ends. No hypertrophy is evident. In infected lateral branches (sporangia?), however, a pronounced swelling occurs (Plate I, Fig. 3, Plate II, Fig. 5). The disintegration of the cell contents is almost complete and there is generally left only a mass of irregularly-shaped, colorless granules. The mature sporangia are nearly spherical and 35–45 μ long by 30–35 μ in diameter. One, or occasionally 2–3 short, stout tubes, 8–10 μ in diameter, are formed through which the mature zoöspores are discharged. Before these are ejected they undergo a period of active swarming, eventually being liberated very rapidly at the dissolution of the tip of the discharge tube. They are minute, being 4 μ long by about 2 μ in diameter, and have a somewhat piriform body (Text Fig. 11), near the broader end of which there is a prominent refractive globule. The position of this globule may change while the spore is motile. Com-

EXPLANATION OF PLATE II

FIGS. 1, 2. *Petersenia lobata,* in *Callithamnion roseum.* Two thalli, showing the peculiar lobing sometimes encountered. × 260.

FIG. 3. *Petersenia sp.,* saprophytic in *Ceramium diaphanum.* An empty sporangium with three discharge tubes visible. × 260.

FIG. 4. Same fungus, showing the spherical, immature thalli and several discharged sporangia. × 260.

FIG. 5. (?) *Olpidium sphacellarum,* parasitic in *Sphacelaria.* Two thalli, one in the colorless hair, the other in the hypertrophied tip of the lateral branch. × 330.

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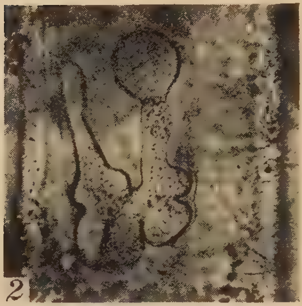
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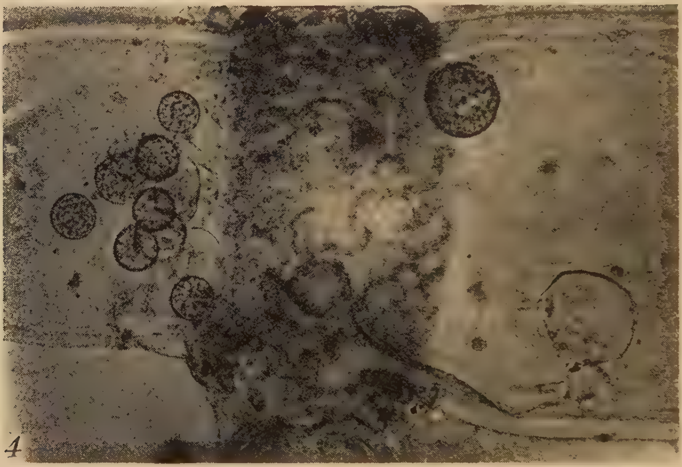
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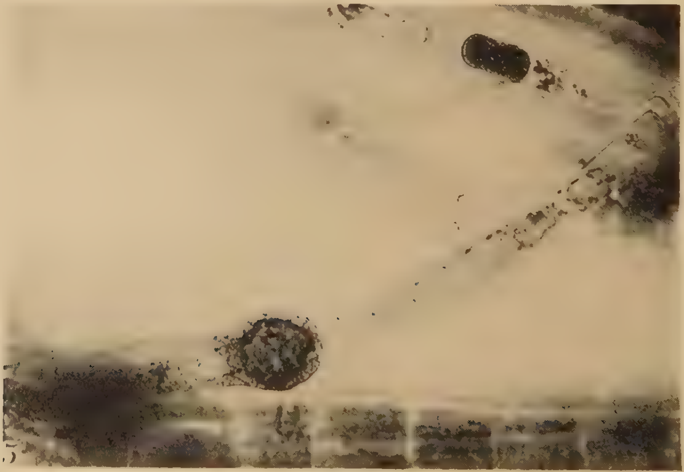
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Plate II

plete data on the ciliation of these spores were not obtained. It is certain that they possessed a very prominent, forwardly directed cilium which appeared to remain nearly stationary during the period of motility. It is probable that another, rapidly vibrating, possibly shorter, posteriorly directed cilium was also present but escaped detection. The zoöspore exhibited a very peculiar type of movement which was characterized by periods of even, forward progression, alternating with sudden stops and change of direction. There appeared to be practically no rotation of the body during movement.

The fungus was a true parasite, invading only the healthy cells of the host and accomplishing alone the disintegration of the contents. With the decline of the alga under laboratory conditions no further fungous activity was noted.

While considered a species of *Olpidium,* it is evident from what is known of the ciliation of the spores that this fungus bears only a superficial resemblance to this genus. If, as is highly probable, the zoöspores are found to be biciliate, it should be placed near *Olpidiopsis* and *Petersenia.*

11. *Pontisma lagenidioides* Petersen. (?) Saprophytic in the internodal cells of *Ceramium diaphanum,* Little Harbor, Woods Hole, July 8, 1934.

Since details of the morphology of this species have been given in a recent paper (Sparrow, 1934), they will not be repeated here. No significant differences from the Danish material were apparent, except for the fact that the Woods Hole fungus (Plate I, Fig. 5) could at the most be called only weakly parasitic on the *Ceramium.* Indeed, only after the alga had been maintained in the laboratory for several weeks did the fungus appear in appreciable quantity. While occasional thalli were formed in apparently living cells free from other organisms, they occurred more commonly in dead and somewhat desiccated algæ along with bacteria and Protozoa.

12. *Sirolpidium bryopsidis* (de Bruyne) Petersen. Parasitic in *Bryopsis plumosa,* Woods Hole, throughout the summer, 1934; June–July, 1935; *Cladophora sp.* (saprophytic?), Woods Hole, July 1, 1935.

EXPLANATION OF PLATE III

FIG. 1. Plant of *Bryopsis plumosa* infected with *Sirolpidium bryopsidis.* The blackened areas caused by the fungus may be seen particularly well along the axes of the lateral branches. About natural size.

FIG. 2. *Ectrogella perforans,* parasitic in *Licmophora abbreviata.* A stand of the diatoms heavily infected with the fungus. Infected cells may be distinguished by the light, spherical sporangia of the *Ectrogella* within them. × 260.

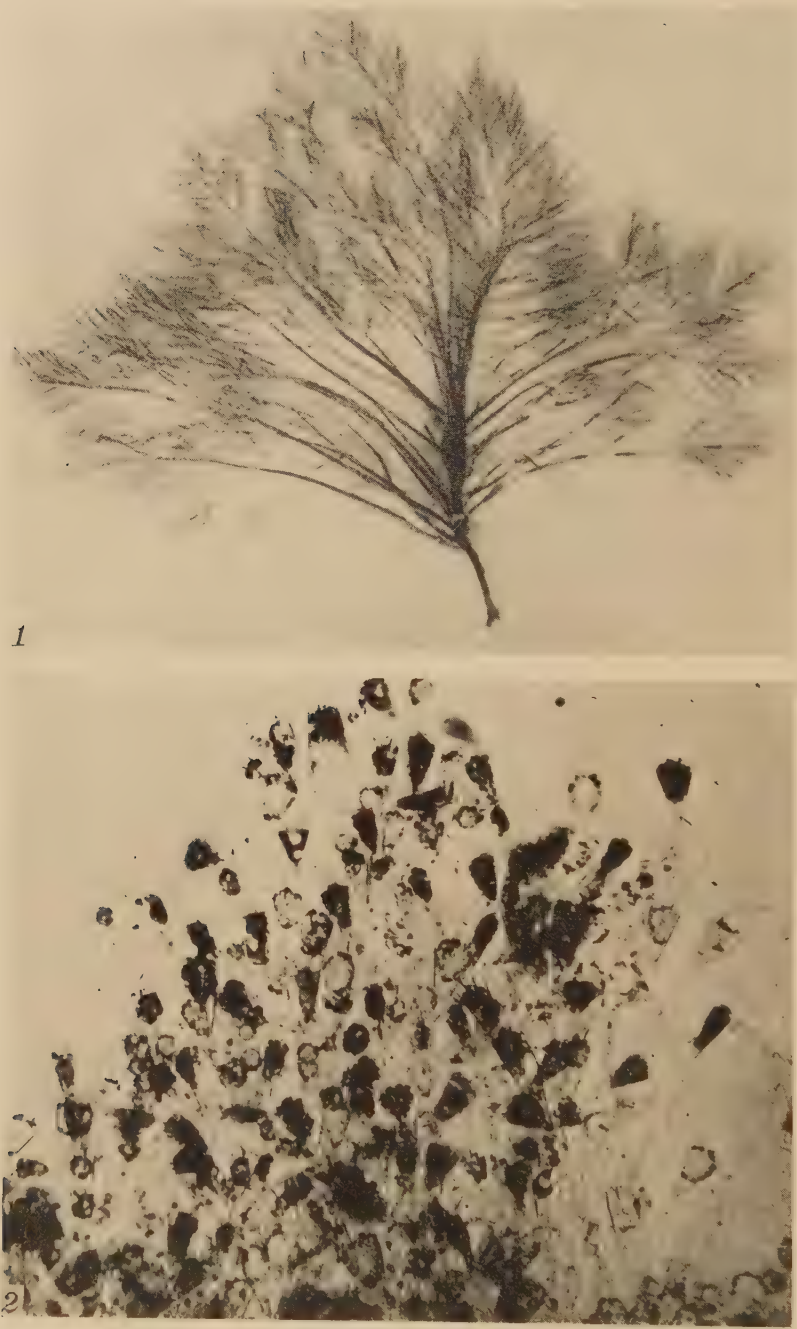


Plate III

As in the preceding case, the Woods Hole material of this fungus showed no morphological differences from that found in Danish waters (Sparrow, 1934) and this phase of the organism will not be dealt with again here. It might be noted, however, that the zoöspore effects penetration of the host cell exactly as in (?) *Olpidium sphacellarum.*

Macroscopically, heavily infected plants may be recognized by the presence of blackened areas along the fronds (Plate III, Fig. 1). The general aspect of the fungus in the alga is shown in the photomicrograph (Plate I, Fig. 4). While early in the course of the infection the fungus undoubtedly acted alone in the entering and the breaking down of the algal contents, in later stages it was often accompanied by swarms of bacteria and Protozoa. Mention has been made already (p. 238) of the peculiar Protomyxa-like animal which often competed with the fungus. Indeed, in some cases this association was so constant that had this animal not been entirely absent in the Danish material, it might easily have been supposed to be a phase in the life history of the *Sirolpidium.*

Since this fungus, by reason of the somewhat filamentous nature of its thallus, seemed the most suitable of these marine fungi for the purpose, attempts of a very preliminary nature were made to culture it. It had been previously noted that if infected *Bryopsis* plants were put in close contact with air, such as allowing water to drip over them rather than to submerge them entirely, the fungus underwent a remarkable transformation in body structure. Instead of the formation of typical olpidioid thalli (Plate I, Fig. 4), there were formed definitely filamentous, ramifying hyphæ (Plate I, Fig. 7). The resemblance of these to the hyphæ of the higher Phycomycetes was very striking.

Pieces of *Bryopsis* containing such hyphæ were placed in various nutrient solutions to determine whether or not further vegetative growth could be induced. Dextrose, mannose, galactose, and fructose were used in Seitz-filtered sea-water solutions of 0.5 per cent and 1.0 per cent and maintained at 19–20° C. Certain protein solutions were tried but fouled too rapidly from bacterial action to be of use. The amount of extramatrical growth was used as a criterion for the efficacy of the particular solution. Suitable controls in Seitz-filtered sea water alone were also set up. Since it was soon found that only the dextrose had a pronounced effect on growth, further solutions of this sugar were made up to determine its most favorable concentration. The results of these preliminary trials are given in Table I.

From these data it can be seen that the lower concentrations of sugar were most effective in stimulating extramatrical growth, whereas the higher concentrations, while they were not lethal to the fungus, seemed to have been definitely inhibitory. Attempts were then made to culture *Sirolpidium* on a solid medium by placing bits of the alga containing extramatrical growth on 0.5 per cent and 1.0 per cent dextrose solutions to which had been added either 0.5 per cent or 1.0 per cent agar. Further growth could not be induced. Studies on the cultivation of *Sirolpidium* are being continued with the hope that from the data obtained from this particularly favorable fungus a method can be devised for getting a number of these organisms into culture. If this can be accomplished, then specific information can be obtained regarding the nature of the activities carried on by these marine fungi.

TABLE I

Extramatrical growth of Sirolpidium in dextrose solutions at 19–20° C.

Solution per cent	Effect on growth			
	24 hours	48 hours	56 hours	80 hours
0.0 (control)	Practically none.	No change.	No change.	No change.
0.5	Excellent growth, up to 100 μ.	Up to 197.5 μ.	No change.	No change; mycelium fragmenting.
1.0	Good growth; up to 62–87 μ.	Up to 112 μ.	No change.	No change; mycelium fragmenting.
1.5	Very little; up to 20–30 μ.	Up to 100–137 μ.	Up to 140 μ.	Up to 175 μ.
2.0	None.	None.	Up to 20 μ.	No change.

13. *Chytridium polysiphoniæ* Cohn. Parasitic on *Polysiphonia fibrillosa,* Woods Hole, August 27, 1934; saprophytic on *Ceramium rubrum,* Woods Hole, August 24, 1934.

Details of the morphology and reproduction of this species are given in a previous paper (1934) by the writer. On *Polysiphonia* (Text Fig. 31), the Woods Hole fungus was an undoubted parasite, whereas it was only saprophytic on *Ceramium,* as was indicated by the whitened and disorganized contents of the alga. Bacteria and Protozoa were abundant in cells of the latter alga, but were absent in infected cells of the *Polysiphonia.*

14. *Chytridium megastomum* Sparrow. Parasitic on *Ceramium diaphanum,* Woods Hole, August 24, 1934.

No morphological differences from the Danish fungus (Sparrow, 1934) could be observed in this material. The sporangia occurred in great numbers on all parts of the alga; bacteria and Protozoa were, however, absent. An interesting feature of the parasitism of this fungus was the fact that the *Ceramium* appeared at the time of observation unaffected by the presence of the *Chytridium.* It seems probable, however, that even though the fungus itself did not exert a marked effect on its host, the innumerable punctures in the cell wall of the alga laid it open to entrance and attack by bacteria, and later, Protozoa. Such a sequence did occur when infected plants were maintained in a laboratory aquarium, but this does not necessarily indicate that such also takes place under natural conditions.

15. *Pleolpidium* (*Rozella*) *marinum* n. sp. Parasitic on *Chytridium polysiphoniæ,* Woods Hole, August 27, 1934.

In material of *Chytridium polysiphoniæ* parasitic on *Polysiphonia fibrillosa,* occasional sporangia were observed which were of larger diameter (30–45 μ) and possessed a thicker wall and more oleaginous contents than others. In several instances these were seen to discharge motile bodies through 1–3 pores (Text Fig. 33). The spores were minute, 3 μ long by 2 μ in diameter, ellipsoid, posteriorly uniciliate, and in contrast to those of *C. polysiphoniæ,* lacked a refractive oil droplet in their content. After a period of swarming, certain ones settled down on the surface of the sporangia of *C. polysiphoniæ* and were observed to produce a fine penetration tube (Text Fig. 32). Further development was not witnessed.

While this fungus might at first sight be considered a multiporous species of *Rhizophidium,* it is in reality a parasite of the *Chytridium,* closely allied to certain fresh-water species usually placed in the genus *Pleolpidium.* Reasons for referring all these species to Cornu's genus *Rozella* have been stated in a previous paper (Sparrow, 1936). Since no marine representatives of this genus have heretofore been described, the fungus is considered a new species, and is termed *Pleolpidium* (*Rozella*) *marinum* n. sp.

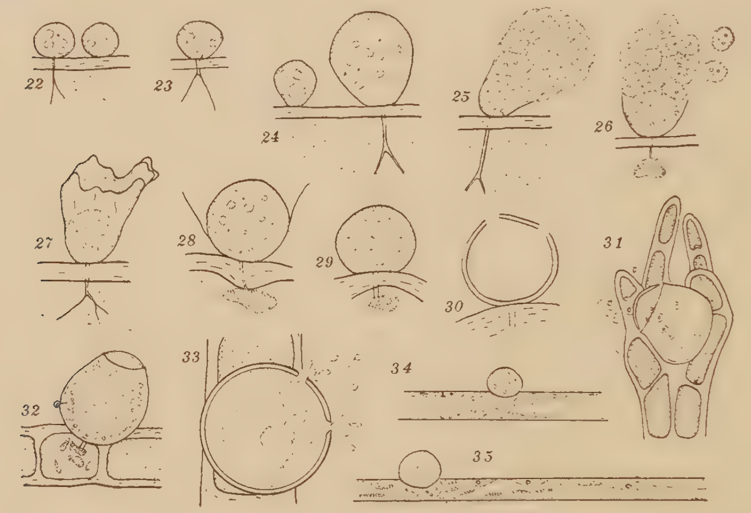
Pleolpidium marinum n. sp. Sporangium spherical, completely filling that of the enlarged host plant; 30–45 μ in diameter, at maturity forming 1–3 pores through which the zoöspores are discharged; zoöspores ellipsoidal, 3 μ long by 2 μ in diameter, posteriorly uniciliate, aguttulate. Resting spores not observed.

Parasitic on *Chytridium polysiphoniæ.*

P. marinum sp. nov. Zoösporangium globosum, cellulam matricis distentam omnino implens, 30–45 μ dia., maturitate 1–3 ostiolatis præditum per quæ zoösporæ emittuntur; zoösporæ ellipsoideæ, 3 μ long. v. 2 μ dia., posteriore uniciliatæ, aguttulatæ. Sporæ perdurante non observatæ.

16. *Rhizophidium discinctum* Petersen. Parasitic(?) on *Ceramium diaphanum,* Woods Hole, August 17, 1934.

A fungus probably identical with that found by Petersen (1905) on *Spongomorpha* and *Acrosiphonia* in Scandinavia was found attacking the nodal cells of the *Ceramium* which had been maintained in a laboratory aquarium for a week. It is probable that the fungus was only weakly, if at all, parasitic on the alga.



Text Figs. 22–35. Figs. 22–28, *Thraustochytrium proliferum,* on *Bryopsis plumosa,* all × 760. Figs. 22–24, various stages in the development of the sporangium; Fig. 25, mature sporangium showing basal body which will become the fundament of the secondary sporangium; Fig. 26, discharge of the zoöspores after the bursting and deliquescence of the upper part of the sporangial membrane; Fig. 27, discharged primary sporangium with secondary sporangium beginning to enlarge; Fig. 28, more mature secondary sporangium. Figs. 29–30, *Rhizophidium discinctum* on *Ceramium diaphanum;* Fig. 29, sub-spherical immature sporangium, × 376; Fig. 30, empty sporangium showing angular aspect and thick wall, × 376. Figs. 31–32, *Chytridium polysiphoniæ;* Fig. 31, discharging sporangium on *Polysiphonia,* × 376; Fig. 32, mature sporangium attacked by a zoöspore of *Pleolpidium* (Rozella) *marinum* × 376. Fig. 33, *Pleolpidium marinum,* Fig. 33, discharging sporangium of the fungus in *Chytridium polysiphoniæ,* × 376. Figs. 34–35, *Rhizophidium globosum*(?) on *Rhizosolenia sp.;* Fig. 34, sporangium with peg-like intramatrical tube, × 376; Fig. 35, sporangium apparently attached to nucleus of host, swarm spores of *Labyrinthula sp.* also attacking diatom, × 376.

The sporangia are at first spherical or hemispherical (Text Fig. 29), but at maturity, because of the formation of one or two laterally-placed discharge papillæ, become more angular. In some cases the upper part of the sporangium may be very definitely flattened. A further characteristic is the thickness of the sporangium wall, a feature very evident in discharged sporangia (Text Fig. 30). Because of the density of the host contents and especially because of the thickness of the algal wall, observations on the nature of the intramatrical system were difficult. So far as could be determined, this structure appeared to consist of a rather stout, unbranched tube. However, it is possible that it branched deeper in the host. Because of this uncertainty it is probably better to keep the fungus in the genus *Rhizophidium* than to transfer it to *Phlyctidium,* where, because of the unbranched rhizoid, it might be placed.

Martin's fungus (Martin, 1922), termed by him *Rhizophidium polysiphoniæ* (Cohn) Petersen, is probably referable to this species.

17. *Rhizophidium globosum* (Br.) Schröt.(?). Parasitic on *Bryopsis plumosa,* Woods Hole, August 8, 1934; saprophytic on *Rhizosolenia spp.,* Woods Hole, August 16, 1934.

The sporangia of the form on *Bryopsis* were spherical, 13–18 μ in diameter, and were attached to the host cell by a delicate, scarcely perceptible, branched, intramatrical rhizoidal system. In contrast to *Rhizophidium discinctum,* the even contour of the sporangium was maintained at maturity.

The fungus attacked only healthy cells of the *Bryopsis.* While the parasite at the time of observation did not appear to have any noticeable effect on the host, it undoubtedly paved the way for the more destructive activities of later invaders.

What may possibly be a closely related form was found in some abundance on cells of *Rhizosolenia spp.* dredged from the bottom of Great Harbor during a heavy "flowering period" of diatoms. The sporangia (Text Figs. 34, 35) were globose to sub-globose, 9–12 μ in diameter, and were generally found singly, attached to the mid-region of the diatom. A single, delicate rhizoid penetrated the alga and possibly attacked the nucleus. Discharge of the zoöspores was not observed and hence, the possibility that we are dealing with a species of *Chytridium* cannot be overlooked.

The fungus on *Rhizosolenium* was found only on obviously disintegrating diatoms, generally in company with a species of *Labyrinthula* (Text Fig. 35) and a *Protomyxa*-like animal. Flagellates were also frequently observed in such cells. No bacteria could be demonstrated in diatoms having both fungus and *Labyrinthula,* or fungus alone, in them.

Both of these fungi are only tentatively referred to the morphologically similar species inhabiting fresh-water algæ.

18. *Thraustochytrium proliferum* n. gen. n. sp. Saprophytic on *Bryopsis plumosa,* July 30, 1934; *Ceramium diaphanum,* August 17, 1934; Woods Hole, Mass.

Thraustochytrium n. gen. Spore upon coming to rest on the host cell encysting and producing an intramatrical rhizoidal system; body of the spore enlarging and becoming the sporangium; spores formed within the sporangium, liberated by the bursting and dissolution of the whole distal portion of the sporangial wall; spores non-ciliate when liberated; new sporangia formed by a process of internal proliferation. Resting spores not observed.

Thraustochytrium gen. nov. Spora cellulæ matricis insidens, encystans ac systema intramatricale rhizoideum proferens; corpus sporæ se maius faciens atque sporangium exsistens; sporæ intra sporangium factæ et eruptione dissolutioneque totius partis distalis parietis sporangialis liberatæ; sporæ non ciliatæ quo tempore liberatæ; nova sporangia ratione proliferationis internæ formatæ. Sporæ perdurantes non observatæ.

T. proliferum n. sp. Sporangia smooth, piriform, very thin-walled, resting on the narrow base; 15.6–18 μ high by 10–13 μ in diameter; rhizoid branched or unbranched, of limited extent; zoöspores somewhat angular at discharge, later becoming spherical, 4 μ in diameter.

T. proliferum[3] sp. nov. Sporangia piriformia, angustæ basi insidentia, levia, pariete tenuissimo, 15.6–18 μ longa, 10–13 μ dia., rhizoidea ramosa aut non ramosa extensionis parvæ; zoösporæ angulosiores quo tempore emissæ, serius sphæroideiores exsistentes, 4 μ dia.

The developmental features of this interesting fungus (Text Figs. 22–24) (Plate I, Fig. 2) are in the main similar to those of *Chytridium* and *Rhizophidium.* However, in the *Thraustotheca*-like discharge of the zoöspores and in the proliferation of the sporangium it possesses two very distinctive characteristics. A further peculiarity is its method of internal proliferation. After the cleavage of the zoöspores there can generally be seen a larger protoplasmic unit occupying the narrow, basal portion of the sporangium (Text Fig. 25). Upon the bursting and deliquescence of the upper part of the sporangial wall by the enlarging zoöspores (Text Fig. 26), these bodies float away leaving only the basal protoplasm (Text Fig. 27). This enlarges (Text Fig. 28) and in time becomes a sporangium. Thus, in contrast to the proliferating sporangia of *Saprolegnia, Pythiomorpha,* etc., the fundament of the secondary sporangium of *Thraustochytrium* is delimited at the time of zoöspore cleavage in the primary body.

There can be no question of the non-ciliate character of the zoöspores at the time of discharge. However, in mounts containing the fungus occasional posteriorly uniciliate zoöspores have been observed which are of the same size as those discharged from the sporangia. Since no other chytridiaceous fungi were found on that particular material of *Bryopsis,* it is entirely possible that after a period of relative quiescence, the spores became ciliate.

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[3] I am indebted to Prof. R. C. Nemiah for the Latin diagnoses of new genera and species given in this paper.

Thraustochytrium differs from its closest relative *Rhizophidium,* in the internal proliferation of its sporangia, in its method of zoöspore discharge, and possibly in the possession of non-ciliate spores.

The fungus was found only on very disintegrated plants of *Bryopsis,* where it sometimes occurred with *Sirolpidium,* swarms of bacteria, and Protozoa.

Discussion

If we turn to a broader consideration of the organisms discussed in this paper, certain points of more general interest are apparent.

Perhaps the foremost of these is the fact that fungi are unquestionably demonstrated to be present in our marine waters. Although their occurrence has been recorded almost wholly from the vicinity of Woods Hole, it is highly probable that they will be found generally distributed in the littoral regions of the United States. While the number of species is as yet small, this does not necessarily imply that they are actually rare, either in kind or number. One need only to compare the bibliographies of fresh-water and marine fungi to appreciate the small amount of investigation that has thus far been accorded the latter group. Undoubtedly, more intensive work will reveal many hitherto unrecorded species.

These preliminary investigations would seem to indicate that the fungous flora in the vicinity of Woods Hole does not differ materially from that found on the other side of the Atlantic. Seven of the 13 fungi collected by the writer in the littoral of the Kattegat have been found at Woods Hole. Further indications of a probably widespread distribution of marine fungi are to be found in *Sirolpidium,* now known from the Gulf of Naples, the Kattegat (Denmark), and Woods Hole, in *Petersenia Andréei,* known from King Charles Land (Arctic), Greenland, Denmark, the Adriatic, and Woods Hole, and in *Eurychasmidium,* known from the North Sea near Edinburgh, the Baltic, and Woods Hole. It is also probable that a fungus from the Adriatic termed *Ectrogella Licmophoræ* by Scherffel (1925) is referable to *E. perforans* Pet., in which case that parasite would now be known from the Adriatic, the Baltic, and the vicinity of Woods Hole. The species of *Labyrinthula* reported by Renn (1934) as being associated with the wasting disease of *Zostera* has been observed by the present writer in diseased material of this plant from the Kattegat (1933), from Woods Hole (1934), and from Plymouth Harbor, England (1935). The organisms from these localities were morphologically indistinguishable. Future work will undoubtedly further corroborate this marked similarity of the floras which is even now so apparent.

Another point of interest is the abundance in the sea of so-called chytridiaceous fungi which possess biciliate zoöspores. While those inhabiting fresh-water algæ are, in the main, uniciliate species (true chytrids), in marine algæ, biciliate forms are more frequently found. From experience in investigating both types of habitat, the writer is inclined to believe that this is a real difference and not an apparent one resulting from the disproportionate amount of work thus far done in the two groups.

As to the question of the abundance of any one species and of the extent to which by its parasitic activities it actually limits the occurrence of a " producer," very little is now known. Of the marine fungi observed by the writer, *Ectrogella perforans* produces the most extensive infection. Indeed, a closer examination of this disease might reveal that, in some instances, it is responsible for the partial or complete disappearance of the diatom from a locality. While it is true that the two diatoms most susceptible to this fungus are littoral types (*Licmophora abbreviata, Striatella unipunctata*), it is not known whether similar epidemics may be produced by *Ectrogella* among pelagic species. In this connection, certain of the peculiar rhythms of " flowering periods " of pelagic diatoms which have been noted in the past and which cannot be attributed to changing physical factors might well be considered from the standpoint of the presence of parasites. Due to the importance of diatoms in their rôle of " producers " in the sea, such a disease as that caused by the *Ectrogella* should be examined in all its aspects, even though at the moment it appears to be confined to littoral algæ. Further, it would be well in the future to give closer attention to the examination of plankton samples for evidences of parasitic organisms, especially during the decline of a " flowering period."

In the formation of " marine humus," as Waksman (1933) has so aptly termed certain types of bottom deposits, future work may show that fungi as well as bacteria play a significant part. It will be recalled that in bottom samples taken in Great Harbor, Woods Hole, during a heavy flowering period of diatoms, two types of fungi were found in some abundance on *Rhizosolenia spp.* (*Labyrinthula* and *Rhizophidium*). Both of these " reducers " were attacking diatoms in all stages of decomposition and many of the algæ must, from their well-organized contents, have either recently fallen to the bottom or had been infected while still alive. Efforts were made to determine whether or not infected diatoms could be observed in samples from surface tows. While such indeed were found, from the nature of the waters in the vicinity of Woods Hole, subject as they are to strong tidal forces, these cannot be taken as proof of infection under pelagic conditions. It is just as possible that they were swept from the bottom as a result of tidal action. Work on the frequency of occurrence of these bottom fungi will be necessary before any estimate can be made of the extent to which they contribute to the general cycle of decomposition in the " humus."

In considering these fungi from the standpoint of their parasitism, we find a wide variation among them. Certain ones (*Ectrogella perforans, Eurychasmidium tumefaciens, Petersenia sp.* in rotifer eggs, (?)*Olpidium sphacellarum, Pleolpidium marinum, Chytridium megastomum* and *Rhizophidium* (?)*globosum* on *Bryopsis*) were true parasites and attacked, unassisted by other organisms, healthy host plants. None of these was ever observed living saprophytically. Other species (*Rhizophidium discinctum* and *Petersenia Andréei*) were only doubtfully parasitic, whereas, *Labyrinthula Chattoni*(?), *Thraustochytrium proliferum, Rhizophidium globosum*(?) on *Rhizosolenia,* and *Petersenia sp.* on *Ceramium* were saprophytes and were found only on dead algal cells. Until it can be shown experimentally that the *Labyrinthula* on decaying diatoms is the same as that parasitic on *Zostera,* it seems better to regard the two as distinct species. *Sirolpidium bryopsidis* and *Chytridium polysiphoniæ* were facultative saprophytes. It might be interpolated here that, while *Pontisma lagenidioides* was observed to be only saprophytic in the vicinity of Woods Hole, in Denmark the fungus was found to be parasitic as well, and hence it should be classed with *Sirolpidium* and *Chytridium polysiphoniæ* as a facultative saprophyte.

It is a pleasure to acknowledge at this time the continued interest of Dr. S. A. Waksman in the progress of these investigations. The writer is also indebted to members of the Botanical Staff of the Marine Biological Laboratory, particularly to Dr. H. Croasdale, for bringing in material of certain algæ.

SUMMARY

In the foregoing paper are described fifteen species of phycomycetous marine fungi, two myxomycetes, and a *Protomyxa*-like protozoan, all collected in the vicinity of Woods Hole, Mass. Included in these are two new genera and two new species. With one exception, the fungi were either parasites, facultative saprophytes, or saprophytes on various species of marine algæ. One was found parasitizing the eggs of a microscopic animal, probably a rotifer. The results of preliminary at-

tempts to culture *Sirolpidium bryopsidis,* a facultative saprophyte of the green alga, *Bryopsis plumosa,* are reported. None of these fungi, with perhaps the exception of *Rhizophidium discinctum,* has heretofore been known from the United States. The existence of true marine fungi, their work as one of the several types of "reducers" in the sea, and their possible importance in the formation of marine humus are discussed in particular.

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Contribution No. 100

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ON THE DEPTH AT WHICH FISH CAN SEE

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At what maximum depth fish can see in the ocean and in lakes has remained a matter for speculation up to the present time, first because little was known regarding the strength of the illumination at various depths and second because no adequate tests of the sensitivity of the fish eye had been made. During the past 10 years, however, the penetration of daylight into natural waters has been carefully studied by a number of investigators in various parts of the world. Furthermore, the recent excellent work by Grundfest ('32) on the sensibility of the sun-fish, *Lepomis,* gives us a reliable yardstick for one species of fish.

In view of the fact that these two sets of data are now available it occurred to me that it would be of interest to calculate the greatest depth in several different types of water at which the sun-fish could just discern an object of a certain size at a given distance. Although the validity of certain assumptions must be granted in order to make such a calculation, it seems probable that we can arrive at the right order of magnitude for this fish. Whether the photosensitivity of other fish is similar to that of *Lepomis* can be decided, of course, only by the performance of suitable experiments. The vision of fish with "telescopic" eyes and of other highly specialized species is undoubtedly on an entirely different scale.[2]

In the experiments on *Lepomis,* which were carried out for quite another purpose, Grundfest made use of the rheotropic response. The fish to be tested was confined in a cylindrical glass jar around which was placed a cylindrical screen composed of equal and alternate vertical bars and spaces and illuminated to any desired intensity by a band of light, 2 mμ wide, from any part of the spectrum. When this screen was rotated in either direction, the fish responded by a sudden movement in the direction of the rotation, provided that the illumination was above a certain threshold the value of which depended upon the part of the spectrum being used. By repeated trials of this sort the spectrum was explored and the spectral sensibility curve determined.

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[1] Contribution No. 100.

[2] A correlation undoubtedly exists between the degree of enlargement or of degeneration of the eyes of deep-sea fish and the depth (and consequently the illumination) at which they live. The issue is confused, however, by important differences which apparently depend upon whether the fish is bottom-living or pelagic and whether or not it possesses light organs. This problem has not yet been satisfactorily elucidated (Murray and Hjort, '12, p. 680).

The fact that the sensibility curve for *Lepomis* shows a sharp peak between wave-lengths 530 and 550 mμ is of interest because it is this general part of the spectrum of daylight which penetrates most effectively into most lakes and into coastal ocean water—the part of the sea in which fish occur in the greatest abundance. The water of the Sargasso Sea, on the other hand, is more transparent to blue light, while in the case of certain lakes and ponds the water contains stains which absorb the shorter wave-lengths so rapidly that the yellow or red component of daylight is found to predominate. H. R. James ('36) has calculated on the basis of laboratory experiments that of the energy of daylight between 300 and 800 mμ which would reach a depth of 100 meters in distilled water 60 per cent would fall in the blue band and only 23 per cent would be in the green. At the surface 17.7 per cent of the energy is in the blue region and 12.3 per cent in the green. These results raise the question of the possibility of a shift in the sensitivity of the eye of a deep water fish toward the blue end of the spectrum.

In Grundfest's experiments the minimum brightness at which the fish would respond for the 2 mμ band in the most effective part of the spectrum corresponded to a brightness of 1×10^{-6} millilamberts for white light as judged by the human eye. Although, theoretically, allowance should be made for the relative effectiveness of other parts of the spectrum since in nature the illumination to which the fish is exposed is obviously not confined to a narrow band, this unfortunately cannot readily be done because of the method used to measure brightness. However, it is extremely doubtful that a large correction would be necessary and since we are attempting to find merely the order of magnitude, this difference may be neglected.

The assumption has tacitly been made that when the fish ceases to respond it no longer "sees" the revolving screen. The further question arises of whether the visibility of a series of bars and spaces moving across the field is the same as that of a single object of the same diameter as the width of the bars. Hecht and Wald ('34, p. 520, footnote) found that slow movement, such as was used in all the experiments with this method, does not affect the visual acuity curve in man. Therefore, since the bars were 2 mm. wide and at a distance of 1 cm. from the fish's eye (thus subtending an angle of about 11°), we may assume that the fish could just see under an illumination of 1×10^{-6} millilamberts an object 2 mm. in diameter at a distance of 1 cm., or a 2 cm. object at 10 cm., or a 20 cm. object at 1 meter, and so on.

Since the sun-fish eye is so much more sensitive to radiation between 500 and 600 mμ than to other regions of the spectrum it is most appropriate to use data for the intensity of submarine irradiation obtained by a photometer, such as one of those employed by Oster and Clarke ('35), with a maximum sensitivity in that region. According to their results the irradiation from 490 to 620 mμ at the surface of the sea off the coast of Massachusetts during the middle of a bright day in summer reaches an intensity of about 20,000 μw/cm.^{2}. In the Sargasso Sea the irradiation at the surface was only slightly greater, having a magnitude of about 25,000 μw/cm.^{2}. Now the minimum brightness for the vision of the sun-fish of 1×10^{-6} millilamberts is equivalent to an irradiation of $1 \times 10^{-6} \times 1.5$ microwatts/cm.$^2 = 1.5 \times 10^{-6}$ μw/cm.^{2}. Since an intensity of 20,000 μw/cm.^{2} is approximately 10^{10} times this, it is apparent that the fish can see under an illumination of 10^{-10} times the maximum value of daylight—or a reduction of ten logarithmic units. This is approximately the same as for the human eye. The instruments which have been found practicable for light penetration investigations have not been sufficiently sensitive to follow the reduction of light in the water for more than three, or at most four, logarithmic units. However, if we assume that the transparency of the water below the maximum depth reached by the photometer is the same as that in the surface strata, the data may be extrapolated. This assumption is justified, to some extent at least, by the fact that in many cases (and in all the cases considered here) there is no radical change in transparency within the depths actually measured. Accordingly, the approximate depth at which the minimum intensity for vision exists (during the hours of bright daylight at the surface) for each type of water investigated has been calculated by finding the average number of meters of water causing a reduction in intensity of one logarithmic unit and multiplying this value by ten.

In so far as it is reasonable to assume that the vision of our common marine fishes is similar to that of *Lepomis,* which inhabits fresh-water ponds and lakes, the figures in the upper part of table I, based on the data of Oster and Clarke, give the extreme depths at which vision would be possible in different types of water. According to these approximations fish would be able to see objects on the bottom in coastal waters. In the case of localities where the " depth of minimum illumination " is much greater than the depth to the bottom, such as Georges Bank, it appears that vision would be possible for fish during most of the day because the intensity of daylight is within one logarithmic unit of its maximum for several hours before and after noon (Clarke and Oster, '34, fig. 6).

Although taste, smell, and touch are undoubtedly used in certain cases for the location of food, most fishes apparently depend chiefly upon sight (Bigelow and Welsh, '24, p. 416 and p. 451). The general conclusion that vision is possible for fish on the bottom in coastal waters is supported by the following observation made by Mr. R. A. Nesbit of the United States Bureau of Fisheries. Mr. Nesbit found that white hake which he took in a bottom trawl at a depth of 132–154 m. off Bodie Island, North Carolina, were gorged with butterfish and other small active fish which presumably the hake could not have caught unless they had been able to see at that depth.

In order to compare these data on fishes with the ability of divers to see under water, I made inquiries of Mr. H. V. Greenough who had been working with conventional diving equipment on a wreck in 29 m. of water in Vineyard Sound about five miles distance from the point off Gay Head where Oster and Clarke had made measurements. Mr. Greenough told me that at that depth tools could be clearly seen at arm's length during several hours in the middle of bright days in July. On one occasion sufficient light existed to permit work on the wreck to continue until 7 o'clock in the evening.

The value arrived at for the Sargasso Sea of 430 meters is of interest in comparison with Beebe's observation from the Bathysphere that complete darkness for the human eye was reached at a depth of between 520 and 580 m. Dr. Beebe has informed me (private communication) that without artificial illumination he was able to see a non-luminous fish four inches long (*Cubiceps*) at a depth of 210 m., a shark at 240 m., and a jelly-fish (*Aurelia*) at 350 m. although entangled luminescent organisms may have aided vision in the last case. In another part of the Sargasso Sea, Helland-Hansen ('31) found that a highly sensitive photographic plate was slightly blackened after an exposure of 80 min. at a depth of 1000 meters. If we assume that a deep sea fish can see as well in blue light as *Lepomis* can in green light, then the maximum depth for vision in the Sargasso Sea would be about 750 meters since an average of 75 m. of this type of water are required for a reduction of one logarithmic unit in the blue region of the spectrum (Clarke, '33).

The depths for the limit of vision for the sun-fish have been similarly calculated for three of the large number of lakes in northern Wisconsin whose transparencies have been carefully studied by Birge and Juday ('31, '32) and for one lake in Minnesota investigated by Erikson ('33), although the different methods used in the measurement of light penetration make comparisons difficult. The values arrived at for these four lakes are set forth in the lower part of table I. Data on the depth at which the energy is reduced to 10 per cent of its surface value for a large number of other lakes are available from the laboratory measurements of James ('36). Crystal Lake is the clearest of all those investigated and Adelaide Lake is one of the most

TABLE I. *Maximum depth for vision of fish similar to Lepomis in various types of water*

Types of water	Thickness of stratum causing reduction of 1 log unit	Depth of minimum illumination for vision of fish similar to *Lepomis* (10 × column 1)	Depth of water to the bottom
Deep Basin of Gulf of Maine	23 meters	230 meters	165 meters
Georges Bank	18	180	60
Woods Hole Harbor	7.5	75	20
Off Gay Head	13	130	30
Sargasso Sea	43	430	4500
Crystal Lake, Wisconsin	11	110	21
Adelaide Lake, Wisconsin	2.8	28	22
Trout Lake, Wisconsin	6	60	35
Gunflint Lake, Minnesota	7	70	50

turbid with the exception of those which are deeply stained. Trout Lake is the deepest of the Wisconsin lakes studied. In all of these and even in Gunflint Lake which is still deeper, the calculations indicate that, just as in coastal waters, vision would be possible for fish similar to *Lepomis* all the way to the bottom.

SUMMARY

It has been calculated from the data of Grundfest ('32) and Oster and Clarke ('35) that the minimum illumination for vision for the sun-fish, *Lepomis,* is approximately 10^{-10} times the maximum value of daylight. The depth at which daylight would suffer a corresponding reduction in different types of ocean water and lake water has been found by extrapolating from existing measurements. The results indicate that for fish whose visual sensitivity is similar to that of *Lepomis* vision would be possible at the bottom in coastal regions and in lakes and at a depth of at least 430 m. in the Sargasso Sea.

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Contribution No. 101

3.

LIGHT PENETRATION IN THE WESTERN NORTH ATLANTIC AND ITS APPLICATION TO BIOLOGICAL PROBLEMS.

BY

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[1]) Contribution No. 101.

DURING the past five years measurements have been undertaken of the penetration of daylight into the sea in both coastal and eanic areas of the Western North Atlantic. The rpose of this investigation was to obtain an curate description of the conditions of illunation at various depths beneath the surface in presentative localities. This information was ught on one hand as essential to the study of e factors controlling the diurnal vertical miation of plankton. Furthermore, a far-reaching nificance must be attached to a knowledge of e amount and nature of the radiant energy neath the sea's surface in relation to the photonthesis of diatoms — the ultimate producers of e sea. Finally, the degree to which light penetes is of interest as determining to what extent ion is possible for fish below the surface zone they go about their daily business.

Methods.

All our observations have been made at sea her from the research vessel "Atlantis" — in f-shore localities — or from the power boat sterias" — in the Woods Hole region. The otoelectric method of measurement developed by oole and Atkins has been employed exusively until recently when a pair of rectifier lls of the "Photox" type produced by the estinghouse Electric and Manufacturing Company s been employed. The arrangement of the photoctric cells in water-tight cases and the carefully sulated potentiometer have been completely scribed by Gall and Atkins (1931). The otox cells are used with a microammeter of ll-scale reading of 25 microamperes with suitable unts for the higher intensities and a diaphragm reduce the size of the receiving window in ong daylight. The characteristics and the stanrdization of the Photox photometer have been ported by Powell and Clarke (1936).

The photoelectric photometers have proved very isfactory especially under conditions of steady umination. Their high sensitivity makes them particularly valuable for exploring the limits of measurable light in deep water. The Photox photometers are more convenient because of their small size and the simplicity of the equipment which is used with them. These photometers are particularly useful for work in situations where the light varies rapidly and a measurement of the average illumination is desired. With the potentiometer method reliable measurements in the upper strata in rough weather are often impossible, but the needle of the microammeter employed with the Photox photometers is so highly damped that it tends to remain at a reading equal to the average value of the fluctuating illumination. Altho less sensitive than photoelectric cells without filters, the Photox photometers, which are sensitive chiefly to the green, were found to respond to practically as weak light as could be measured by the photoelectric photometer when limited by filters to the green part of the spectrum. Table I summarizes the characteristics of the various photometers employed (See also Clarke, 1933 a; Clarke and Oster, 1934; and Oster and Clarke, 1935).

Comparative Transparency of Different Types of Atlantic Water.

The measurements of light penetration which have been undertaken in areas of the North Atlantic ranging from mid-ocean to Continental Shelf and in-shore waters reveal a profound variation in transparency. The extremes of this variation are illustrated in Fig. 1 in which the transparencies of four types of water to the blue component of daylight are compared. Taking the depth at which the light is reduced to 1 $^0/_0$ of its surface value as a convenient method for visualizing differences in transparency, it is seen that in Woods Hole Harbor such a reduction is found at a depth of only 8 m. while in the Sargasso Sea the 1 $^0/_0$ value is not encountered until a depth of 149 m. is reached. The water of the deep basin of the Gulf of Maine is intermediate with a depth of 32 m. for a reduction to 1 $^0/_0$. A transparency similar to that

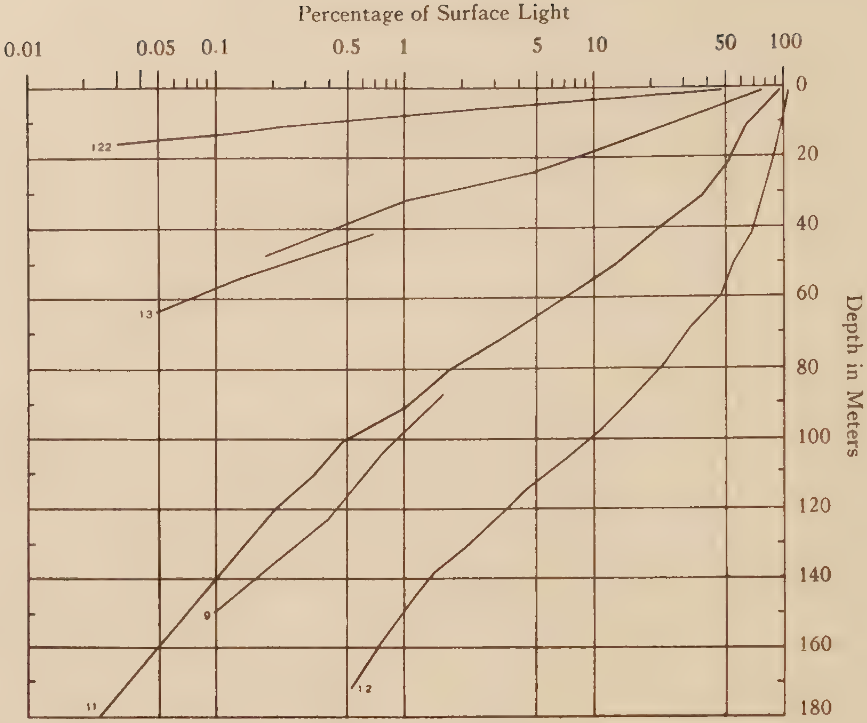

Fig. 1. Comparison of transparencies of four areas in the North Atlantic to the "blue" component of daylight.

Series 9 — near Azore Islands.
„ 11 and 12 — Sargasso Sea.
„ 13 — Gulf of Maine.
„ 122 -- Woods Hole Harbor.

Table I.

Characteristics of Photometers Employed.

Maximum Spectral Sensitivity.	Range of Sentitivity.	Type of Cell.	Filters Used.	Irradiation within ran of sensitivity necessar to produce current of 1 µa.
		Photoelectric Cells1)		
"Blue"	3460—5260 A°	Potassium (sensitized)	None	135—315 µw/cm
"Blue"	3460—5260 A°	Potassium (Gas-filled and sensitized)	None	63
"Violet"	3100—4500	Potassium (unsensitized)	None	181
"Red"	6000—7000	Caesium	Schott-Jena RG—1 and $CuCl_2$ solution	1340
"Green"	4900—6200	Caesium	Schott-Jena BG—18 and GG—11	1885
		Rectifier Cells1)		
"Green"	4650—6250	Copper-oxide (Photox)	None	7

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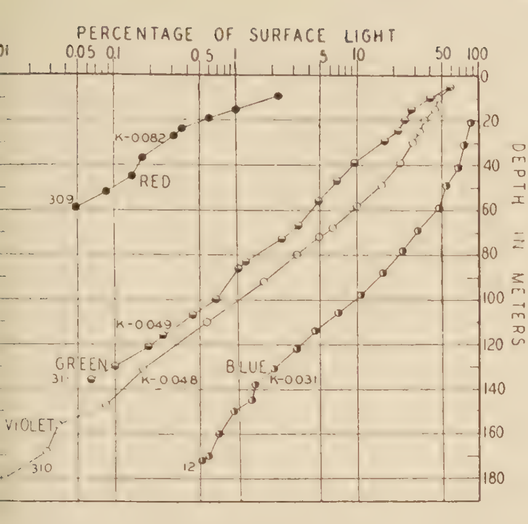
1) The minimum current which can be measured by the potentiometer used with the photo-electric cells is 0. 0.005 µa depending upon the dark current. The minimum current which can be measured using the microar employed with the Photox cells is about 1 µa.



'ig. 2. Penetration of daylight in Sargasso Sea and Gulf Stream.

Series 309 — Station 2243.
„ 310 and 311 — Station 2245.
„ 12 — Station 1041.

he Gulf of Maine typifies mid-Atlantic water latitude 52° N., but from this point south the sparency was found to increase rapidly arke, 1933 a).

Not only do the coastal and oceanic areas inigated vary profoundly in general clearness also they differ in their relative transparency lifferent parts of the spectrum. A comparison the penetration of the red, green, blue, and et components of daylight into three represen-e types of water, may be made from Figs. 2, nd 4 which show the conditions in the Sargasso and Gulf Stream, in the deep basin of the f of Maine, and in Vineyard Sound and Woods e Harbor respectively.

The water in the Sargasso Sea and Gulf Stream found to be more transparent than any other on in the world where observations have been le (with the possible exception of the Mediter-ean where Grein (1913—14) obtained cer-high but doubtful values). In fact, the rness of the water is so great in this part of ocean that the values of the transmissive onent, k, approach — and in one case surpass Clarke, 1933 a) — those for distilled water letermined by Sawyer (1934). In this type water blue light penetrates best, green and et are about equal, and the red component is t rapidly absorbed.

A measurement in the Gulf Stream south of Grand Banks (Station 2484) was kindly carried for me by Mr. Alfred Woodcock on tember 15, 1935, using the Photox photometers en sensitive). The value of the transmissive onent was $k = 0.082$ from 2 m. to 10 m. From n. to 95 m. the transparency was found to be

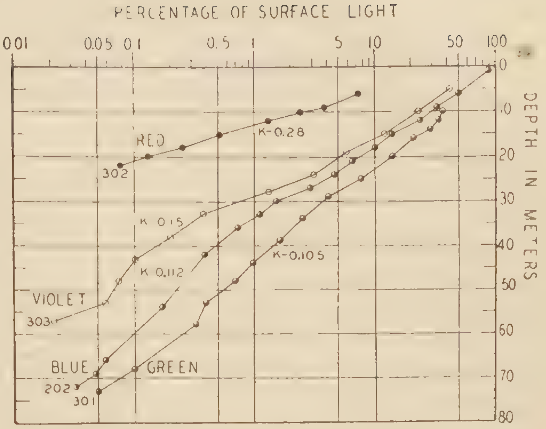


Fig. 3. Penetration of daylight in deep basin of Gulf of Maine.

Series 301, 302, and 303 — Station 2237.
„ 202 — Station 1722.

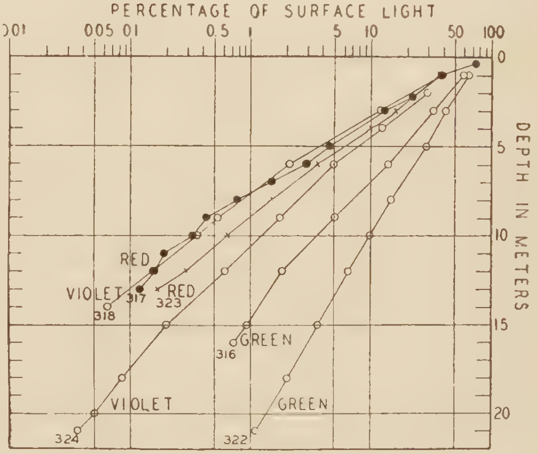


Fig. 4. Penetration af daylight.

Series 322, 323, and 324 — Vineyard Sound.
„ 316, 317, and 318 — Woods Hole Harbor.

extremely uniform with a value of $k = 0.057$. The water at this station was therefore only slightly less transparent to green light than was the case at the stations north of Bermuda (Table II) which are about 1000 miles distant.

The transparency of the deep basin of the Gulf of Maine appears to be characteristic of coastal water well out on the continental shelf. The values obtained in this area are generally similar to those reported by Atkins and Poole (1933) for the English Channel and by Utterback and Jorgensen (1934) for a point 28 miles off Vancouver Island. In the Gulf of Maine the blue and green components penetrate

Table II.

Comparison of Average Values of the Transmissive Exponent, k,[1]) in Oceanic and Coastal Areas of the Western North Atlantic (Arranged in order of decreasing transparency).

Locality	Station	Position	"Red"	"Green"	"Blue"	"Vio
Sargasso Sea, E of Bermuda ...	1041	36°55′ N 52°41′ W	—	—	0.031	—
Gulf Stream, N of Bermuda	2245	37°35′ N 68°44′ W	0.13	0.049	—	0.0
Sargasso Sea, N of Bermuda ..	2243	35°52′ N 65°30′ W	0.082	0.050	—	0.0
Gulf Stream, S of Grand Banks.	2484	39°56′ N 48°40′ W	—	0.059	—	—
Continental Slope, S of Nantucket Shoals	2246	39°27′ N 69°43′ W	0.23	0.074	—	0.0
Deep basin of Gulf of Maine ..	2237 (+ 1722)	42°08′ N 69°04′ W	0.28	0.11	0.112	0.1
Continental Shelf, S of Cape Cod	2474	40°48′ N 71°00′ W	—	0.11	—	—
Georges Bank	2238 (+ 1723)	40°48′ N 68°40′ W	0.35	0.13	0.14	0.1
Off Gay Head	—	41°20′ N 70°57′ W	0.37	0.16	0.27	0.2
Vineyard Sound	—	41°30′ N 70°36′ W	0.46	0.20	0.36	0.3
Provincetown Harbor	—	42°03′ N 70°11′ W	—	0.23	—	—
Buzzards Bay	—	41°33′ N 70°42′25″ W	0.50	0.25	0.51	0.4
Woods Hole Harbor	—	41°31′ N 70°40′ W	0.56	0.30	0.49	0.5

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1) In the equation $I/I_0 = e^{-kL}$ where L is the thickness of the water layer (in meters) in which the intensit
reduced from I_0 to I.

about equally well. For violet light the transmission is slightly lower but for red it is only half as great as for the blue and green.

The low transparency found in Wood Hole Harbor and Vineyard Sound is characteristic of inshore waters generally, the conditions here being similar to the San Juan Archipelago (Utterback and Boyle, 1933) and Baltic Sea waters (Pettersson and Landberg, 1934). In these localities the green component of daylight penetrates the most effectively; the red, blue, and violet components are absorbed much more rapidly and do not differ greatly among themselves. Altho it has long been known that many lakes and ponds are relatively opaque, the magnitude and universality of this fact in comparison with ocean water was brought home to us only when we discovered that the transmissive exponent for green light for the clearest lake water ever tested (Crystal Lake, Wisconsin, cf. Birge and Juday, 1931—32) is almost exactly the same as our value for Vineyard Sound.

All the localities where measurements have been made in the Western North Atlantic are arranged in order of transparency in Table II and the average values of the transmissive exponents for the four components of daylight are compared. To generalize from this table we see that the Sargasso Sea is 2 to 4 times more transparent than the Gulf of Maine and the latter is 3 to 4 times more transparent than Woods Hole Harbor. The exact amount of the difference depends upon which part of the spectrum is compared; for example, the transparency of the Sargasso Sea is greater than
that of Woods Hole Harbour by the follow
factors for different parts of the spectrum: 6X
green, 7X for red, 11X for violet, and 16X
blue. In other words the great increase in tra
parency experienced in going from inshore wa
to oceanic regions consists chiefly in a very ex
sive improvement in the penetration of the sho
wave-lengths.

Reflection and Absorption at the Surface.

In the foregoing measurements and in those
other investigators a "loss" of considerable m
nitude has often been encountered at the surf
Attempts to measure the light present just bene
the surface of the water for comparison with t
just above the surface have usually been unsucc
ful because the action of the waves and the mot
of the ship have made it impossible to keep
submarine photometer in the desired position l
enough to make a measurement. Furthermore,
light for several meters below the surface f
tuates so rapidly that it is very difficult to ob
a reliable reading at these levels particularly w
using the potentiometer method. The result is
the depth of the first point of observation
often not been less than 5 meters in off-sh
localities and occasionally no satisfactory meas
ment could be obtained short of 10 m. When
curves representing the penetration of light f
the first point downwards are extended upwa
to zero depth, it is commonly found that they st

abscissa at points indicating a reduction in the it at the very surface of from a few per cent. to or 60 %. This discrepancy has been termed the rface loss".

During the past summer measurements were ried out (Powell and Clarke, 1936) to ermine whether large surface losses actually do st or whether they could be accounted for by ie instrumental or observational error. In ad- on it was hoped that it would be possible to inguish between the loss due to reflection at surface from the apparent loss which would be duced by a stratum of less transparent water ch might have existed undetected just beneath surface.

The incident light I at the surface of the sea may divided into three components: A, that which etrates the surface and is entirely absorbed he sea; R, that which is reflected either at the oth surface of the water or by white foam and bles on the surface; and U, that which pene- es the surface but is scattered back by par- es and bubbles in the water below and finally rns to the air. Therefore,

$$I = A + R + U.$$

The magnitudes of the three components A, R, U may be determined by placing a photometer various positions relative to the sea surface and nparing the values obtained with I, the intensity nd with the receiving surface of the photometer ced upwards and horizontal. If the instrument uspended over the sea in an inverted position, neasures the quantity $R + U$ which is the total it coming upward from the sea's surface. If the tometer is lowered in an inverted position to a nt just beneath the surface, U can be measured ne.

The total light passing downwards through the face is $A + U$, but this quantity cannot be isured directly with precision as already ex- ined. However, since I, U, and $R + U$ can all accurately measured, the values of A and R ie can be calculated. The quantity $R + U$ is of ticular interest as being that fraction of the it falling on the ocean which does not contri- e to its supply of energy. The remaining light, ch is the quantity A, is absorbed by molecules water, by bubbles, by suspended particles, and organisms. This component is the entire source heat for the ocean (if infrared radiation is uded) and is responsible for all the photo- mical reactions of marine organisms.

The light passing upward from the surface of sea was measured by suspending the "deck" tometers in an inverted position at the top of a ting tower constructed of pipe and mounted on rels. The heavy "sea" photometers were inted on gimbals and used to measure the illu- ation on deck. Since the light from the sur- of the water fluctuates rapidly the potentiometer method which gives an instantaneous measurement could not be used satisfactorily. In its stead a circuit involving a thyratron tube and relay was employed. The relay was so arranged that each time it became excited it moved the escapement of a watch thus registering the number of discharges and allowing the intensity of the light to be integrated over any desired period of time.

When the Photox rectifier cells had been procured further reflection measurements were made by mounting one of them in a light case and attaching it to the end of a long bamboo pole. In this way the photometer was held about 4½ m. out over the side of the boat and measurements were made with the receiving window turned alternately upward and then downward.

The obervations on the total upward light, or $R + U$, made with the red, green, and violet sensitive photometers showed that only a slight difference exists in the values for these components of daylight. $R + U$ for red light was almost always somewhat lower than for violet and green was intermediate as would be expected from their relative indices of refraction.

$R + U$ reaches a minimum (about 4 % for violet and 3 % for red) on clear days when the sun is nearest the zenith; on cloudy days the value may reach 6 or 7 %. After the sun has fallen below about 44° from the horizon the value of $R + U$ begins to rise. Below 30° on a clear day $R + U$ becomes steadily higher, and is higher then than under any other conditions. From 12° on the inaccuracy introduced by the unavoidable tilting of the photometers invalidates the measurements but there is every indication that $R + U$ becomes very high as predicted by theory. For solar altitudes of 12° to 30° $R + U$ ranged between 6 and 20 % in clear weather. White caps were found to increase $R + U$ only slightly, apparently because the foam produced covers a relatively small proportion of the total surface. This is in agreement with a value of 12 % obtained over the foamy part of the boat's wake. Altho the magnitude of the upward light has been found to remain an inconsiderable fraction of the incident light under all conditions, it must be remembered that its percentage may be two or more times greater on one occasion than on another and its absolute value varies with the strength of daylight.

Since these results point to a much lower value for the loss of light at the surface than was indicated by previous measurements of submarine illumination, an attempt was next made to measure with more care and precision than before the intensity of the light just below the surface.

Under conditions of absolute calm, clear sky, and glassy smooth water in Buzzards Bay it was possible to make measurements up to within 10 cm. of the surface where 97.5 % of the light was transmitted (Series 401, Fig. 5). The trend of the

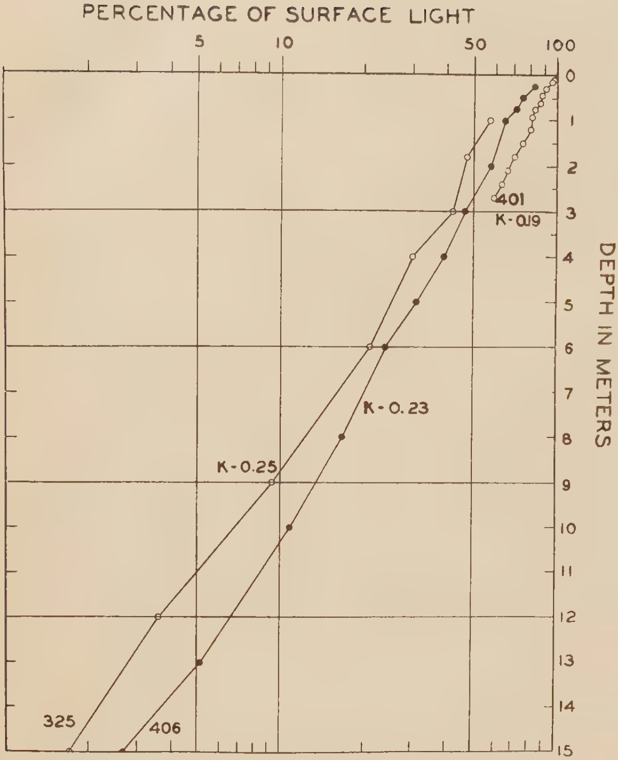

Fig. 5. Penetration of daylight showing "surface loss" under different conditions.

Buzzards Bay: Series 325. Slight sea.
„ 401. Glassy smooth sea.
Provincetown Harbor: Series 406. Slight sea.

curve is straight from this point to a depth of 2.7 meters. When the curve is extrapolated to zero depth a value of about 100 $^0/_0$ is reached. A short time later when the sun was about 35° from the horizon $R + U$ was found to be 8.4 $^0/_0$. Since the theoretical reflecting power, R, for light incident at this angle as calculated from Fresnel's law of reflection for a smooth water surface is 5 $^0/_0$, the value of U alone must have amounted to about 3.4 $^0/_0$ or almost half of the total upward light.

The situation is entirely different when the surface of the sea is disturbed as is revealed by a comparison with Series 325 made at the same place the year before on a day when small waves existed. If the curve is extrapolated beyond the 1 meter level, a "surface loss" of about 30 $^0/_0$ is indicated. Since the value of the transmissive exponent for the upper 6 meters ($k = 0.19$) is identical with that for Series 401, the difference in the position of the two curves cannot be due to a difference in the transparency of the water on the two occasions. Furthermore, we know from our present investigation that $R + U$ could not have been as great as 30 $^0/_0$. It was therefore suspected that the stratum of water less th
1 meter thick just beneath the surface beca
relatively opaque when the surface of the sea w
rough and that this condition disappeared in ca
weather.

Such a situation was actually detected
measurements made in Provincetown Harb
(Series 406) on a clear day with wind force
(Beaufort Scale), small waves, and occasion
flecks of foam. If the curve is extrapolated
zero depth using only points below 1 meter
indicates a surface loss of 15 $^0/_0$ or more.
when one extrapolates from points above 0.5 me
a loss of only 6 $^0/_0$ is found. In this case $R +$
was 4.6 $^0/_0$ and U, measured directly by inverti
the sea photometer and lowering it a few cen
meters beneath the surface, was 3 $^0/_0$. The abru
change of slope in the curve reveals the increas
rate of absorption and scattering within the fi
meter of water.

In the open sea with waves a meter or more h
and white caps, values for $R + U$ of 5.5 a
4.6 $^0/_0$ were obtained at stations on Georges Ba
and south of Cape Cod respectively. At the lat
station it was possible in addition to make s
marine measurements from a depth of 50 met
up to 0.5 meters (Series 412, Fig. 6). Without t
last point on the curve the surface loss appe
to be 14 $^0/_0$ while with it the loss is redu
to almost nothing.

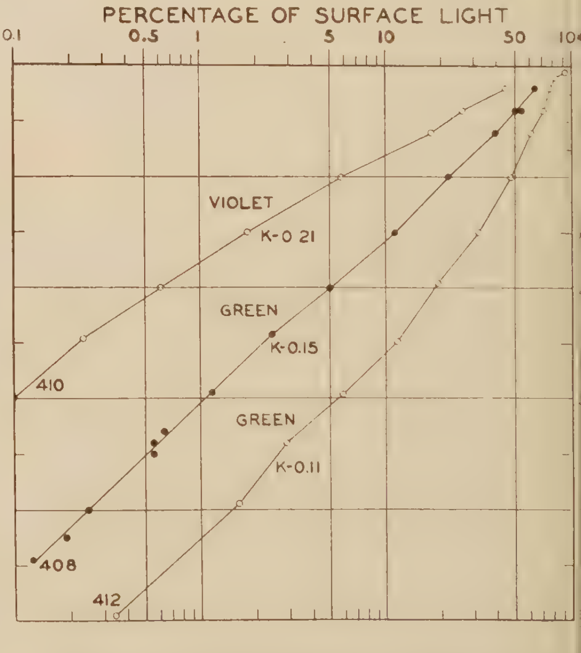

Fig. 6. Penetration of daylight showing presence o
"opaque layer" just beneath surface.

Georges Bank: Series 408. Moderate sea.
„ 410. Moderate sea.
South of Cape Cod: Series 412. Moderate sea.

From the foregoing observations we may con-
de that the discrepancies which have been termed
rface losses" are not due chiefly to a "loss" at
very surface. They are due, however, to a
tum of relatively opaque water which exists just
eath the surface and which has generally
aped notice.

The average value of all our measurements of
$+ U$ for solar altitudes greater than 30° is about
% for cloudy days and about 4 % for clear
s. Differences in the condition of the sea
face ranging from flat calm to waves with
te caps has very little effect on these figures.
value of $R + U$ was not more than a few units
her in the more opaque inshore waters than in
clearer water of the Gulf of Maine. $R + U$
ever more than 9 % except for solar altitudes
ater than 30° in clear weather. These
ditions would exist during only a small portion
the day for most of the ocean, but the greater
ection losses at lower solar altitudes is un-
btedly of considerable importance in polar seas.
values of $R + U$ of 9 % or less, R and U
e found to be about equal in magnitude. There-
e, the portion of daylight which never enters
water at all, namely R, is never more than a
per cent. of the incident light and consequently
negligible importance. These results agree very
sely with measurements of the reflection from
surface of certain rivers and of Chesapeake
made by Kimball and Hand (1930) from
aeroplane of altitudes varying from 10 to
0 ft.

Under conditions of absolute calm the trans-
ency of the water remains unchanged up to
hin at least 10 cm. of the surface. The "surface
" deduced from extrapolation is very small and
agreement with the low magnitude of the re-
tion. But as the sea's surface becomes more
more disturbed, the "surface loss" discrepancy
omes larger and larger. Its magnitude is usually
ut 15 % but has often been reported as much
ater. Since we have found that the value of
U does not become significantly larger under
gh conditions than in calm weather, it follows
the amount of light absorbed in the upper
er or so has greatly increased. Careful in-
igation of this stratum has proved that this is
eed the case.

The cause of this diminished transparency of
surface layer is undoubtedly the presence of
bles produced by a disturbance of the water.
mical substances, particles of sediment, and
nktonic organisms are uniformly distributed
a much greater depth than the thickness of
anomalous stratum by the vertical mixing
duced by turbulence. In every case where a
e "surface loss" has been recorded either white
s or a tide rip has existed. In calm weather
phenomenon disappears.

Rate at which Submarine Light becomes Diffuse.

The upward component of light beneath the surface was measured with an inverted photometer at each meter to a depth of 14 m. in Provincetown Harbor where the depth is about 16 m. At 0.5 m. the upward component was found to be 4 % of the downward component and this ratio increased gradually to a value of 6 % at 14 meters. In Buzzards Bay (depth 15 m.) the ratio was found to be 4.8 % at 1 m., 5.8 % at 5 m., and 8.9 % at 10 m. In the deep basin of the Gulf of Maine a ratio of 2.5 % was obtained at 0.5 m. and this value remained unchanged to a depth of 20 m.

A few approximate measurements of the horizontal component of the submarine illumination were made by suspending the sea photometer by one end so that the receiving surface was vertical. The photometer was caused to rotate slowly around a vertical axis in order that the window might face successively in all directions relative to the direction of the sun which was unobscured. A maximum and minimum intensity was thus recorded for each depth. In Provincetown Harbor the ratio of the maximum value for horizontal illumination at 1.5 m. to the vertical downward illumination at the same depth was 16 % and the ratio of the minimum horizontal illumination to the vertical illumination was 3.4 %. At 10 m. these ratios had increased to 17 % and 7 %, respectively. In the deep basin of the Gulf of Maine the ratios were 6 % and 3 % at 2 m., and 20 and 3 % at 15 m. Poole and Atkins (1929) reported an average value of 50 % for the horizontal light down to 25 m. in the English Channel. It is seen, therefore, that the illumination becomes more and more diffuse with increasing depth, but the directional character of the light is lost only slowly. One recalls that Helland-Hansen (1931) found that the vertical light was measurably greater than the horizontal at 500 m. in the Sargasso Sea.

Diurnal Vertical Migration of Zooplankton.

Many of our measurements of light penetration have been made in connection with the study of the diurnal migration of copepods (Clarke, 1933b, 1934a and b). From careful records of illumination on deck throughout the day and several measurements of the transparency at the station where plankton hauls were being made, it was possible to construct diagrams which showed the changes both in the vertical distribution of the animals and in the intensity of light at the different depths. From an analysis of these it was hoped that the factors controlling the migration might be unraveled.

If there is one generality which can safely be made about the migration of plankton, it is that the phenomenon is an extremely variable one. Not only do different species behave differently, but the reaction of the same species may be quite contrary in one locality to what it is in another, or in the same locality at different times, as Russell (1934) has shown so clearly. If this were not enough, we find that the sexes and the various age groups of the same species in the same body of water often exhibit the most diverse behavior ranging from no migration at all to very extensive and rapid vertical movements (cf. Nicholls, 1933).

For those cases in which a clear cut diurnal migration is found the change in intensity of daylight during each 24 hour period is undoubtedly the most important single cause. In our investigations in the Gulf of Maine the migration of copepods was found to be much more closely correlated with the changes in submarine irradiation than with the changes in the hydrographic conditions or in the phytoplankton. In addition, light is of further significance because it is one of the two physical factors of the environment to which a copepod can respond *directionally*, as I have pointed out elsewhere (Clarke, 1934c). Light, gravity, and possibly stimuli from other organisms appear to be the only forces which can bring about orientation and thus make a consistent movement possible. At depths where the illumination has become so diffuse that the direction of propagation is no longer perceptible to the copepod, phototropic responses cannot take place. The intensity of the light present may, however, affect the sign of geotropism.

Altho light is generally conceded to play a major role in diurnal migration, the manner in which it exerts its effect is by no means clear. It may be that plankton animals are positively phototropic to weak light and negative to strong light. On the other hand it has been suggested that such influences as feeding or change of temperature may control the sign of the phototropic movement rather than the intensity of the illumination. But if phototropism alone is acting it is difficult to understand why the animals continue to move toward the surface after dark, as is often observed to be the case, or why they sometimes leave the surface before dawn. In these cases it seems to me more reasonable to suppose that light acts thru a modification of, or interference with, a persistent geotropism. According to this idea the negative reaction to light is thought to overpower the negative geotropism during the morning and noon hours but is less effective in the afternoon when light-adaptation has taken place. In cases where withdrawal from the surface occurs before dawn we would have to assume that some other factor acting in the upper strata reversed the geotropism after a certain number of hours.

For animals which remain continually in t deeper strata we may postulate a positive ge tropism, and for those that swarm near the surfa even during the middle of bright days, we m assume a negative geotropism which is strong than any tendency to move away from the lig But the validity of these assumptions must tested by suitable experiments in the laborato and more precise observations at sea before a of these explanations can be excepted. The pictu which seems to emerge from all this, however, one of a plankton whose physiological adjustme are in a very delicate balance. Evidently ve slight changes in the environment or undetectal differences in the internal physiological states different ages or sexes or broods are sufficient completely reverse the sign of the reactions.

The Metabolism of Diatoms.

Since the photosynthesis of diatoms is of su fundamental importance in the sea, it is unf tunate that we do not have more information the needs and limitations of this process in relati to the distribution of submarine illumination. the western side of the Atlantic three experime have been carried out in which the metabolism diatoms was measured in bottles suspended different depths in the sea, some of which w covered with black cloth and others of which w left exposed to the radiant energy existing in surrounding water.

For the experiments in Woods Hole Harbor a in the Gulf of Maine (Clarke and Ost 1934) phytoplankton from hauls made near was suitably diluted and placed in the gl stoppered oxygen bottles. In the Woods H Harbor experiment, which was undertaken collaboration with Professor H. H. Gran, plankton was exposed for four hours during middle of the day. At the end of that time it found that the oxygen consumed in respiration just balanced by the oxygen evolved in pho synthesis at a depth of about 7 meters — the "c pensation point". The fact that at 18 meters loss in oxygen in the exposed bottles was not great as in the covered bottles shows that measurable amount of photosynthesis took plac the extremely weak light which penetrates to t depth, altho the photosynthesis was obviou much less than the respiration.

In the Gulf of Maine experiment, which carried out by Professor A. C. Redfield, exposure period extended from five o'clock in morning to 2 o'clock in the afternoon. During time the "compensation point" occurred at 2 30 meters, but some photosynthesis was dete down to 40 meters. The water in the Gulf Maine is roughly three times as transparent as Woods Hole Harbor and the "compensation po lies about three times as deep.

It is of interest to compare with these results 1 experiment carried out for me by Mr. S. S. ellis in the Sargasso Sea where the radiant nergy is so much more intense. Since the diatoms rowing naturally in this area could not readily procured in sufficient concentration to produce easurable changes in the oxygen bottles, a perstent culture of *Nitzschia closterium* was used for is experiment. However, the photosynthesis of is northern diatom under the unnatural contions of high temperature and intense illumiation may have been very different from that hich would have resulted had it been possible to e a native species. This possibility must be borne mind when interpreting the results (Table III). ut since this is the only experiment of its kind in opical oceanic water to my knowledge, the data em valuable as a first approximation.

Table III.

Metabolism of Diatoms in Sargasso Sea.

ersistent culture of *Nitzschia closterium* used.
xposure Period: 1050—1650, Aug. 24, 1934.
ky: clear. Sea: smooth.
xygen present before exposure: 7.62
7.57
7.51
av. 7.57 cc./liter.

Depth meters.	Temp. C.	Condition of bottles.	Oxygen after exposure cc./l.	Change in oxygen cc./l.	Difference in exposed and covered bottles cc./l.
0	24.0	Covered	7.78	+ 0.21	
		Exposed	11.22	+ 3.65	+ 3.44
		Exposed	11.15	+ 3.58	+ 3.37
0	21.5	Covered	7.51	— 0.06	
		Exposed	13.45	+ 5.88	+ 5.94
		Exposed	13.48	+ 5.91	+ 5.97
0	20.2	Covered	7.70	+ 0.13	
		Exposed	14. 11	+ 6.54	+ 6.41
		Exposed	14.90	+ 7.33	+ 7.20
00	19.5	Covered	7.68	+ 0.11	
		Exposed	11.71	+ 4.14	+ 4.03
		Exposed	11.41	+ 3.84	+ 3.73
0	19.1	Covered	7.60	+ 0.03	
		Exposed	9.87	+ 2.30	+ 2.27
		Exposed	9.75	+ 2.18	+ 2.15
0	18.9	Covered	8.01	+ 0.44	
		Exposed	8.51	+ 0.94	+ 0.50
		Exposed	8.25	+ 0.68	+ 0.24

The results in this experiment are unfortunately t as regular as was the case in the Gulf of Maine rk and considerable difference is found between ttles in the same categories. Furthermore, all the vered bottles except one showed a slight increase oxygen instead of a decrease as they should if ey are to be used as a measure of respiration alone. Possibly the light which reached them during manipulation at the beginning and end of the experiment was sufficient to account for this. However, if one assumes that this error was the same for all the bottles at each level, we may find the amount of photosynthesis which occurred at the designated depths by subtracting the oxygen produced in the covered bottle from that produced in the exposed bottles, altho the location of the "compensation point" is unfortunately impossible.

The differences in the amount of oxygen produced in the exposed bottles at the different levels is so very great that in spite of these irregularities we may draw two rather significant conclusions. In the first place it is seen that the greatest amount of photosynthesis is found at the 80 meter level. Evidently the more intense illumination (or possibly the higher temperature) of the upper strata exerted an inhibitory effect. This is in sharp contrast to the other experiments in which the largest production of oxygen took place just under the surface. The other conclusion of interest is that a considerable amount of photosynthesis went on even at a depth of 140 meters — 100 meters deeper than the lowest level of detectable oxygen production in the Gulf of Maine series.

These three experiments give an impression of the depth to which photosynthesis may extend in three different areas of the sea. They do not, however, show the thickness of the stratum in which constructive production goes on during the whole 24 hours of the day or longer periods (cf. Marshall and Orr, 1928; and Pettersson, Höglund, and Landberg, 1934). This is obviously the significant information from the point of view of the fertility of the sea and it is to be hoped that more extensive experiments will be undertaken in the near future on this problem — particularly in the great oceans.

The Depth at which Fish can see.

At what maximum depth fish can see in the ocean and in lakes has remained a matter for speculation up to the present time, first because little was known regarding the strength of the illumination at various depths and second because no adequate tests of the sensitivity of the fish eye had been made. However, the recent work by Grundfest (1932) on the sensibility of the sun-fish, *Lepomis*, has provided us with reliable values for one species of fish. With this information and our present knowledge of the penetration of light it is possible to make an approximate calculation of the greatest depth in several different types of water at which the sun-fish could just discern an object of a certain size at a given distance. Whether the photosensitivity of other fish is similar to that of *Lepomis* can be decided, of course, only by the performance of suitable experiments. The vision of fish with "telescopic" eyes and of other highly specialized species is undoubtedly on an entirely different scale[1]).

Grundfest tested the response of the sun-fish to the movement of a screen illuminated by bands of light in different parts of the spectrum and found that radiation between wave-lengths 530 and 550 mμ was much the most effective. It is this general part of the spectrum of daylight which penetrates most effectively into most lakes and into coastal ocean water — the part of the sea in which fish occur in the greatest abundance. The minimum illumination, in the most effective region of the spectrum, under which the fish would respond was 1×10^{-6} millilamberts. Since the bars of the screen used in the experiment were 2 mm. broad and at a distance of 1 cm. from the fish's eye (thus subtending an angle of about 11°), we may assume that the fish could just see under this minimum illumination an object 2 mm. in diameter at a distance of 1 cm., or a 2 cm. object at 10 cm., or a 20 cm. object at 1 meter, and so on.

The irradiation from 490 to 620 mμ at the surface of the sea off the coast of Massachusetts during the middle of a bright day in summer reaches an intensity of about 20,000 microwatts/cm^2. Now the minimum brightness for the vision of the sun-fish of 1×10^{-6} millilamberts is equivalent to an irradiation of 1.5×10^{-6} μw/cm^2. Since an intensity of 20,000 μw/cm^2 is approximately 10^{10} times this, it is apparent that the fish can see under an illumination of 10^{-10} times the maximum value of daylight — or a reduction of ten logarithmic units. This is approximately the same as for man. The instruments which have been found practicable for light penetration investigations have not been sufficiently sensitive to follow the reduction of light in the water for more than three, or at most four, logarithmic units. However, if we assume that the transparency of the water below the maximum depth reached by the photometer is the same as that in the surface strata, the data may be extrapolated. This assumption is justified, to some extent at least, by the fact that in many cases (and in all the cases considered here) there is no radical change in transparency within the depths actually measured. Accordingly, the approximate depth at which the minimum intensity for vision exists (during the hours of bright daylight at the surface) for each type of water investigated has been calculated by finding average number of meters of water causing a duction in intensity of one logarithmic unit multiplying this value by ten.

Table IV.

Maximum depth for vision of fish similar to *Lepor* in various types of water.

Types of water.	Thickness of stratum causing reduction of 1 log unit.	Depth of minimum illumination for vision of fish similar to *Lepomis* (10 × column 1)	
	m.	m.	
Deep Basin of Gulf of Maine	23	230	
Georges Bank	18	180	
Woods Hole Harbor	7.5	75	
Off Gay Head	13	130	
Sargasso Sea	43	430	45
Crystal Lake, Wisconsin	11	110	
Adelaide Lake. Wisconsin ..	2.8	28	
Trout Lake, Wisconsin	6	60	
Gunflint Lake, Minnesota ..	7	70	

In so far as it is reasonable to assume that vision of our common marine fishes is similar that of *Lepomis*, which inhabits fresh-water po and lakes, the figures in the upper part of Table give the extreme depths at which vision would possible in different types of water. Accordin these approximations fish would be able to objects on the bottom in coastal waters. In case of localities where the "depth of minim illumination" is much greater than the depth to bottom, such as Georges Bank, it appears vision would be possible for fish during most the day because the intensity of daylight is wit one logarithmic unit of its maximum for seve hours before and after noon. Altho taste, sm and touch are undoubtedly used in certain ca for the location of food, most fishes appare depend chiefly upon sight. The general conclus that vision is possible for fish on the bottom coastal waters is supported by the following servation made by Mr. R. A. Nesbit of United States Bureau of Fisheries. Mr. Nes found that white hake which he took in a bot trawl at a depth of 132—154 m. off Bodie Isla North Carolina, were gorged with butterfish other small active fish which presumably the h could not have caught unless they had been to see at that depth.

In order to compare these data on fishes the ability of divers to see under water, I m inquiries of Mr. H. V. Greenough who been working with conventional diving equipn on a wreck in 29 m. of water in Vineyard So about five miles distance from the point off ead where our light penetration measurements ad been made. Mr. Greenough told me that that depth tools could be clearly seen at arm's ngth during several hours in the middle of bright ays in July. On one occasion sufficient light isted to permit work on the wreck to continue ntil 7 o'clock in the evening.

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[1]) A correlation undoubtedly exists between the degree of enlargement or of degeneration of the eyes of deep-sea fish and the depth (and consequently the illumination) at which they live. The issue is confused, however, by important differences which apparently depend upon whether the fish is bottom-living or pelagic and whether or not it possesses light organs. This problem has not yet been satisfactorily elucidated. *Cf.* Murray and Hjort (1912, p. 680).

The value arrived at for the Sargasso Sea of 30 meters is of interest in comparison with eebe's observation from the Bathysphere that omplete darkness for the human eye was reached a depth of between 520 and 580 m. Dr. Beebe as informed me (private communication) that ithout artificial illumination he was able to see non-luminous fish four inches long *(Cubiceps)* a depth of 210 m., a shark at 240 m., and a lly-fish *(Aurelia)* at 350 m. altho entangled minescent organisms may have aided vision in e last case. If we assume that a deep sea fish n see as well in blue light as *Lepomis* can in reen light, then the maximum depth for vision in e Sargasso Sea would be about 750 meters since average of 75 m. of this type of water are quired for a reduction of one logarithmic unit the blue region of the spectrum.

The depths for the limit of vision for the sunfish have been similarly calculated for three of the large number of lakes in northern Wisconsin whose transparencies have been carefully studied by Birge and Juday (1931, 1932) and for one lake in Minnesota investigated by Erikson (1935), altho the different methods used in the measurement of light penetration make comparisons difficult. The values arrived at for these four lakes are set forth in the lower part of Table IV. Crystal Lake is the clearest of all those investigated and Adelaide Lake is one of the most turbid with the exception of those which are deeply stained. Trout Lake is the deepest of the Wisconsin lakes studied. In all of these and even in Gunflint Lake which is still deeper, the calculations indicate that, just as in coastal waters, vision would be possible for fish similar to *Lepomis* all the way to the bottom.

Acknowledgement.

I wish to acknowledge the valuable collaboration of Dr. R. H. Oster and Dr. W. M. Powell in this investigation.

Summary.

1. Measurements of the penetration of four omponents of daylight have been carried out in oth coastal and oceanic areas of the western North tlantic using photoelectric cells with a marine otentiometer and, more recently, rectifier cells of e "Photox" type with a suitably damped micronmeter.

2. The water in the Sargasso Sea and Gulf ream was found to be more transparent than in y other region of the world. The transparency the Gulf of Maine is 2 to 4 times lower than is and is characteristic of coastal water on the ntinental shelf. The water in Woods Hole Harbor 3 to 4 times less transparent than in the Gulf of aine and is representative of inshore waters gerally and of lakes. The transparency of the rgasso Sea is greater than that of Woods Hole arbor by the following factors: 6 × for green ght, 7 × for red, 11 × for violet, and 16 × r blue.

3. The "surface loss" was investigated by spending a photometer in an inverted position er the surface of the water and measuring the tal light passing upward ($R + U$). In Buzzards ay, $R + U$ reaches a minimum of 3 to $4\,^0/_0$ on ear days when the sun is nearest the zenith. The rcentage is increased by one or two units when aves exist and by a few units more when the sky is cloudy, and is decreased by a few units in clearer off-shore waters. The greater part of the "surface loss" is due to a stratum of relatively opaque water which extends in rough weather to a depth of about 1 meter.

4. Measurements of the upward and horizontal components of the light beneath the surface showed that illumination becomes more and more diffuse with increasing depth, but the directional character of the light is lost only slowly.

5. Light is the most important factor controlling the diurnal migration of plankton and it is one of the two physical factors to which a copepod can respond directionally. However, it has been found that the reactions of the plankton to light are easily altered by slight changes in the environment or in the internal physiological state.

6. Experiments on the metabolism of diatoms in relation to light penetration were carried out in Woods Hole Harbor, in the Gulf of Maine, and in the Sargasso Sea. A measurable amount of photosynthesis was found to occur down to depths of 18 m., 40 m., and 140 m. in the three localities respectively. The "compensation point" for periods of a few hours occurred at 7 m. in Woods Hole Harbor and at 24 to 30 m. in the Gulf of Maine. An inhibiting effect was observed above 80 m. in the Sargasso Sea.

7. The minimum illumination for vision for the sun-fish, *Lepomis*, is approximately 10^{-10} times the maximum value of daylight. The depth at which daylight would suffer a corresponding reduction in different types of water has been calculated. The results indicate that for fish of sim
visual sensitivity vision would be possible at
bottom in coastal regions and in lakes and
depth of at least 430 m. in the Sargasso Sea.

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Contribution No. 103

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DREDGE-SAMPLES FROM THE SUBMARINE CANYONS BETWEEN THE HUDSON GORGE AND CHESAPEAKE BAY

H. C. Stetson

(Contribution No. 103 from the Woods Hole Oceanographic Institution)

In August, 1935, the research vessel Atlantis of the Woods Hole Oceanographic Institution made a dredging trip to the outer part of the Hudson Gorge, to two valleys cutting the continental margin off the Delaware coast between 30° 30' and 38° 06' north latitude, and to one off Maryland lying between 37° 30' and 37° 20' north latitude. With the exception of the outer gorge of the Hudson, these canyons are in every way similar to those described by Shepard from Georges Bank, and their general configuration is too familiar to everyone to warrant further description here (F. P. Shepard, Canyons off the New England coast, Amer. J. Sci., v. 27, pp. 24-36, 1934). In many places the slope of the walls is apparently above the angle of repose of unconsolidated material, and presumably cliffs of truncated strata form part of the canyon walls. It is not the purpose of this preliminary report to enter into a discussion of the origin of these features. We are only concerned here with the nature of the material found within the canyons themselves. Whatever their origin may have been, it is obvious that factors were once in operation the dating of which would be of importance to geologists. Last summer's reconnaissance was a continuation of the problem begun the preceding year on Georges Bank, namely, of attempting to fix the maximum age of these valleys by means of fossiliferous samples dredged from their walls and, secondly, of gaining some knowledge of the type of material of which the continental margin is composed.

Dredging operations are carried on in the following manner: The edge of a valley would be located by echo-soundings and buoy placed on it. The vessel would proceed slowly toward the middle of the valley until a steep cliff had been crossed. The course would be reversed and the dredge lowered and the depth recorded. The ship would then go ahead at about two knots laying out wire at the same speed to avoid kinking, the dredge meanwhile remaining stationary. Experience showed that about one mile of wire was necessary to assure a good angle of drag for this type of work at the depth at which the cliffs were found. The winch was then stopped and the vessel allowed to fetch up on the dredge and drag it up the face of the cliff. At times the dredge would anchor itself securely enough to check the vessel's headway. Tows were always made uphill and only the lower and upper limits could be recorded since the vessel was far ahead of the dredge. It is not possible, therefore, to fix the exact depth at which any single formation was encountered. The vertical range of each tow, however, was not great and in no case amounted to more than 300 meters.

It was anticipated from what we know of the structure of the Coastal Plain that the older formations found in the Georges Bank canyons would not be encountered in the canyons from the Hudson Gorge southwards, and such proved to be the case. The Coastal Plain formations constitute a wedge of nearly flat-lying sediments, with the thin edge at the Fall Line, dipping gently seaward and thickening as they go. They rest upon a beveled platform of igneous and metamorphic rock, itself with a seaward tilt, which physiographers term the Fall Line peneplain. The seaward dip of the beds averages from 40 to 50 feet per mile for the early Cretaceous formations to 10 to 15 feet per mile for the later Tertiary. At Atlantic City, New Jersey, well-borings have shown the top of the Miocene (Kirkwood) to be already 390 feet down, and at Wildwood, 300 feet (J. V. Lewis and H. B. Kümmel, The geology of New Jersey, Geol. Surv. N.J., Bull. 14, 1915). It is a matter of common observation that the continental shelf off this part of the Atlantic Coast is an extension of the Coastal Plain. If the same structural conditions as we know them on land hold reasonably constant for the seaward portion, and we have no reason for supposing that they do not, the upper parts of the canyons must necessarily be cut in very young strata. The steepest slopes of the valley-walls are apparently restricted to a zone about 200 to 800 meters below present sea-level. The depth at which these steep slopes are found below the top of the continental shelf is only a small portion of the depths of the canyons. Furthermore, at the continental margin there apparently is still a considerable thickness of sedimentary material below the valley-bottoms [Maurice Ewing and others, Geophysical investigations in the emerged and submerged Atlantic Coastal Plain, Part I--Methods and results, abstract Geol. Soc. Amer., Pr., 1935 (1936)]. Experience had shown in the case of the Georges Bank canyons that the only places where material could be obtained, which was not the product of present-day sedimentation, were in this zone of cliffs, likewise occurring at about the same depths. Elsewhere, because of lesser gradients, present-day accumulation has covered the older sediments with a mantle too thick to be penetrated by any sampling apparatus. This likewise was found to be the case in the southern canyons.

Let us now examine the different types of sediments which were found in the canyons. Twenty-three tows were made in all, thirteen of which yielded material very different from the sediment at present being deposited on the continental shelf and slope and in the valleys themselves. Fourteen cores were also taken with the explosion-type coring tube recently designed by C. S. Piggot. In the canyons at depths below 100 to 150 meters this modern sediment is a green, sandy silt becoming somewhat finer with increasing depth, but at the depths of water at which the tows were made the median diameter of the size-distribution ranges from about 0.06 to 0.1 mm. The sorting is poor because of the large admixture of sand. It is entirely unconsolidated and easily washed through the large mesh of the bag on the dredge. Smears of it, however, were almost always present when the dredge came on deck. It appeared in the top portions of nearly every core, and a great many of them chiefly from the valley-bottoms and gentler slopes were composed of it throughout. A few years ago two lines of bottom-samples were run by the Woods Hole Oceanographic Institution from the shore over the break in slope, the first one between the Hudson Gorge and the canyon immediately to the south, and the second falling by chance between the two southernmost canyons. These sediments from the top of the shelf were sands of varying degrees of coarseness, while those from the slope consisted of the same oozy green silt becoming finer with increasing depth.

The other materials found within the canyons are easily distinguishable from the foregoing by the degree of compaction and frequently by their texture. The material came up in angular chunks with freshly broken faces--pieces sufficiently hard in some cases to be nearly dry inside. In spite of the rough handling they received, worm-tubes and the burrows of various bottom-living organisms are preserved intact. Occasionally, seaweeds were found growing on some of the faces, showing that they were in direct contact with the water. No surface-deposits could ever attain the degree of compaction displayed here. In a tow from the southernmost valley the dredge came up full of fragments of a coarse-grained, highly indurated sandstone which unfortunately was unfossiliferous. These were obviously talus blocks, as they were weathered on all sides. The outcrop itself was never found. The most common are vari-colored clays, with median diameters ranging from about 0.002 to 0.001 mm and with poor sorting. Nowhere on the continental slope as far as is known do we find sediments at comparable depths approaching these clays in fineness of texture. It is not till much greater depths are reached, at stations well outside the continental margins, that similar median diameters are found. Occasionally silts were brought up having about the same values for median diameters and sorting as this unconsolidated green silt, which is the product of present-day sedimentation. These, however, are distinguished from the former by the compaction as noted above.

Dr. J. A. Cushman has examined the foraminifera from these compacted samples and states that they are all living forms, and that, though their exact geologic range is unknown, they can not be older than late Pleistocene. The living foraminifera of the unconsolidated green silt constitute a fauna easily distinguished from that of the compacted samples, and little duplication of species is found between the two.

As outlined above, the texture and compaction serve to differentiate sharply the samples just described from what is known to be the product of present-day deposition in this region. They must, therefore, be from an older formation, and they must have been laid down at a time when environmental conditions were very different from what they are today. It was to be expected that the upper parts of the canyon-walls would be cut in young material, but this does not necessarily imply Recent or even late Pleistocene.

In the case of the Georges Bank canyons, the narrowly restricted vertical range of the fossiliferous material, its relationships to deposits of glacial outwash and present-day silt, and the position of the Cretaceous-Tertiary contact support the assumption that it was obtained from truncated strata forming the actual walls, not from the fill of a preexisting cut (H. C. Stetson, Geology and paleontology of the Georges Bank canyons, Part I--Geology, Bull. Geol. Soc. Amer., v. 47, pp. 339-366, 1936). The youngest material obtained has been shown to be late Tertiary, probably dating from late Pliocene times (Joseph A. Cushman, Geology and paleontology of the Georges Bank canyons, Part IV--Cretaceous and late Tertiary Foraminifera, Bull. Geol. Soc. Amer., v. 47, pp. 413-440, 1936.

In the southern canyons the case is not so definite. The vertical range through which the material is found is greater, and there are no discernible contacts. Furthermore, though the evidence is strictly negative, it seems scarcely credible that the valleys could have been formed by either subaerial or submarine agencies since the deposition of material which is so youthful. MacClintock and Richards have recently placed in the Sangamon interglacial stage the widespread Gardiners formation of Long Island and southern New England, and the Cape May formation of New Jersey, both of which contain much clay (Paul MacClintock and Horace G. Richards, Correlation of late Pleistocene marine and glacial deposits of New Jersey and New York, Bull. Geol. Soc. Amer., v. 47, pp. 289-338, 1936. We are certain that the material under discussion is not the product of present-day sedimentation, but the strong possibility does exist that we may be dealing with the offshore component of Sangamon deposition which was laid down as fill in an older cut. Subsequent slumping and landsliding down the canyon-walls of stiff heavy clay of this sort would produce an irregular topography with many steep cliff-faces as is demonstrated in the case of Gay Head, Martha's Vineyard. If the material were thick enough, it could easily pile up at the base of any preexisting cliffs and effectively mantle the older formations below. The peculiar position of Georges Bank, which is separated from the mainland by the deep basin of the Gulf of Maine, may have prevented extensive deposition of this material in the canyons cutting its margin.

The study is not yet complete, but at the present writing we may draw the following conclusions:

(1) Material was dredged from the sides of the outer Hudson Gorge and from three canyons south of it, which is Recent and late Pleistocene, but which clearly is not the produce of present-day deposition.

(2) In contrast to the evidence previously obtained from the Georges Bank canyons, the dredged material may have come from the fill of an older cut and not from outcrops of truncated strata forming the actual walls.

(3) It is suggested that this material may be the offshore component of deposition which occurred during the Sangamon interglacial stage, and which resulted on land in the Gardiners formation of Long Island and southern New England and the Cape May formation of New Jersey.

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REPORTS AND PAPERS, OCEANOGRAPHY--1936

THE INFLUENCE OF THE MEDITERRANEAN OUTFLOW AT MID-DEPTHS IN THE SARGASSO SEA

Columbus Iselin

(Contribution No. 104 from the Woods Hole Oceanographic Institution)

It has been known for some time that in the eastern North Atlantic the salinity at mid-depths (500-2000) is often relatively high. There is no doubt among those who have examined the question that this is largely due to the outflow of water from the Mediterranean. Owing to the high rate of evaporation in the Mediterranean two currents are to be expected in the Straits of Gibraltar, namely, an inflow of Atlantic water at the surface and an outflow of relatively saline water along the bottom. Such currents have been frequently observed. The outflowing water leaves the Mediterranean with a salinity of about 38 o/oo, and according to Nielsen its volume averages 56,200 km^3 per year.

The salt that this current carries is absorbed into the Atlantic at mid-depths, for the Mediterranean water is relatively heavy and, after flowing across the shallow sill of the Straits, it sinks downward along the continental slope to about 1200 meters before spreading seaward. During its passage through the Straits and in the process of sinking, the original salinity of 38 o/oo is much reduced by mixing. Thus through turbulence enough normal Atlantic water is quickly absorbed into the Mediterranean outflow to reduce the salinity to a value of about 36.45 o/oo in the heart of layer at 1200 meters just off the Straits. While the amount of superficial Atlantic water which is thus drawn downward cannot be exactly calculated, for it is not known just where and at what depth the greater part of the mixing takes place, this admixture undoubtedly amounts to several times the volume of the pure Mediterranean water. Thus the so-called Mediterranean water in the North Atlantic is in reality largely superficial Atlantic water which has

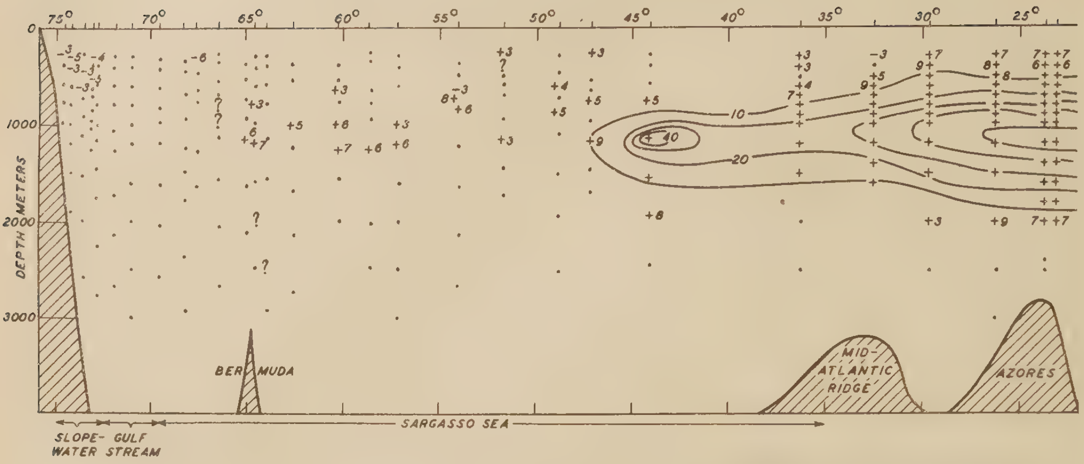


FIG. 1—SALINITY-ANOMALIES ON A SECTION RUNNING FROM THE EDGE OF THE CONTINENTAL SHELF OFF CHESAPEAKE BAY TO

been drawn into the vigorous downward mixing which takes place just off the Straits of Gibraltar.

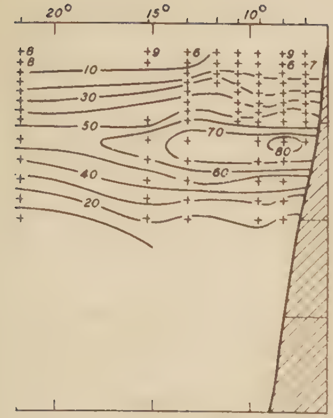
It was at first thought that, because of the effect of the Earth's rotation, the layer of maximum salinity at mid-depths must exert its main influence towards the north as it moves outward from its source. Indeed, the early observations seemed to support this view, because high salinities at 1200 meters were soon traced northward to the area southwest of Ireland. However, as more stations were made southward and westward from the Straits of Gibraltar, it became evident that the outflow of Mediterranean water was quite symmetrical.

In a recent paper by Wüst the full extent of the Mediterranean's influence in the Atlantic has been for the first time pointed out. In a series of most instructive charts this author has followed the main tongue, bearing a considerable admixture of Mediterranean water westward to mid-ocean. By a new method he has even shown that, from this layer of the North Atlantic, salt is supplied to the deep currents of the South Atlantic. It is now evident that the Mediterranean is largely responsible for one of the major differences between the waters of the Atlantic and the Pacific. Not only is the great depth of the isohaline of 35 o/oo in the Sargasso Sea thereby explained, but we can now much better understand the way in which saline water is brought to the deep layers of the Southern Hemisphere.

In studying the Atlantis stations from the Sargasso Sea, the influence of the Mediterranean water has been examined by the method of salinity-anomalies. Since this procedure has proved most instructive in the case of slow lateral movements at mid-depths, it may be of interest to briefly describe the procedure and to show some of the results arrived at in the case of the upper North Atlantic deep water, as Wüst has named the layer carrying Mediterranean characteristics.

In the preliminary examination of the data, it was found that many of the stations from the neighborhood of Bermuda gave identical temperature-salinity correlation-curves. However, at occasional stations one or more observations at mid-depths showed departures from the average conditions that were greater than could be accounted for by the observational error. Such departures can conveniently be recorded as the parts per hundred thousand in salinity by which the sample in question differs from water of the same temperature at the stations of the standard curve. Observations having salinities higher than given by the average curve were recorded as positive and those lower as negative. From these anomalies, sections were constructed of the various lines of Atlantis stations crossing the Sargasso Sea. In this way it was found that the small positive anomalies occasionally met with near Bermuda could be traced back to the Mediterranean outflow.

In the section of Figure 1 given as an example of the salinity-anomaly method, the stations run in a nearly straight line from the mouth of Chesapeake Bay on the west to Gibraltar on the east. The western half of the profile is based on Atlantis stations, while the eastern half comes from the results of various European expeditions. The anomalies at depths between 0 and 250 meters have not been plotted, as this layer is subject to seasonal changes, nor are any readings recorded from below 3000 meters. A small dot on this section indicates an observation that



THE STRAITS OF GIBRALTAR

does not differ from the standard curve by more than the error of the salinity-determination (±0.02 o/oo). Anomalies having values of between three and ten parts per hundred thousand have been recorded on the diagram. Those positive and greater than ten have been shown by a small +, the approximate values being indicated by the contour-lines. No negative anomalies greater than ten appear in this particular section.

An examination of Figure 1 shows in the west some small negative anomalies from the thermocline layer of the slope-water. This band, between the edge of the continental shelf and the Gulf Stream, is always slightly fresher for a given temperature than western Sargasso Sea water. Then near Bermuda at depths of between 800 and 1200 meters some small positive anomalies first appear. These can be clearly traced back to the much higher values of the so-called Mediterranean water in the eastern half of the ocean. It is also evident that in the central Sargasso Sea the positive anomalies are found at slightly shallower depths than those occupied by the main tongue of Mediterranean water. This is explained when we remember that the clockwise, superficial currents of the Sargasso Sea do not probably extend down to more than moderate depths. Therefore, positive anomalies are seldom carried westward from the under side of the wedge-shaped mass that gives anomalies greater than ten. Thus from the standpoint of the Sargasso Sea, the Mediterranean water exerts its greatest influence at moderate depths, the deeper positive anomalies being probably for the most part carried southward into the South Atlantic.

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Contribution No. 105

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COMPUTATION OF THE TRANSPORT OF SURFACE-WATER DUE TO THE WIND-SYSTEM OVER THE NORTH ATLANTIC

R. B. Montgomery

(Contribution No. 105 from the Woods Hole Oceanographic Institution)

One of the most important forces which maintains the circulation of the ocean is that exerted directly on its surface by the wind. It is even assumed by some that the frictional force of the wind is the primary cause of most of the large-scale currents of the open ocean. Taking advantage of the recent improvements in the theoretical machinery necessary for computing the direct effects of the wind, I have attempted to compute one of these effects on a large scale, namely, the transports of the drift-currents resulting from the mean wind-distribution over the North Atlantic.

The general theory of ocean-currents by Ekman says that the effect of the wind is to produce a drift-current whose velocity decreases with depth according to a spiral, and which is essentially limited to the surface 50 or 100 meters. The unequal convergence of this current at different

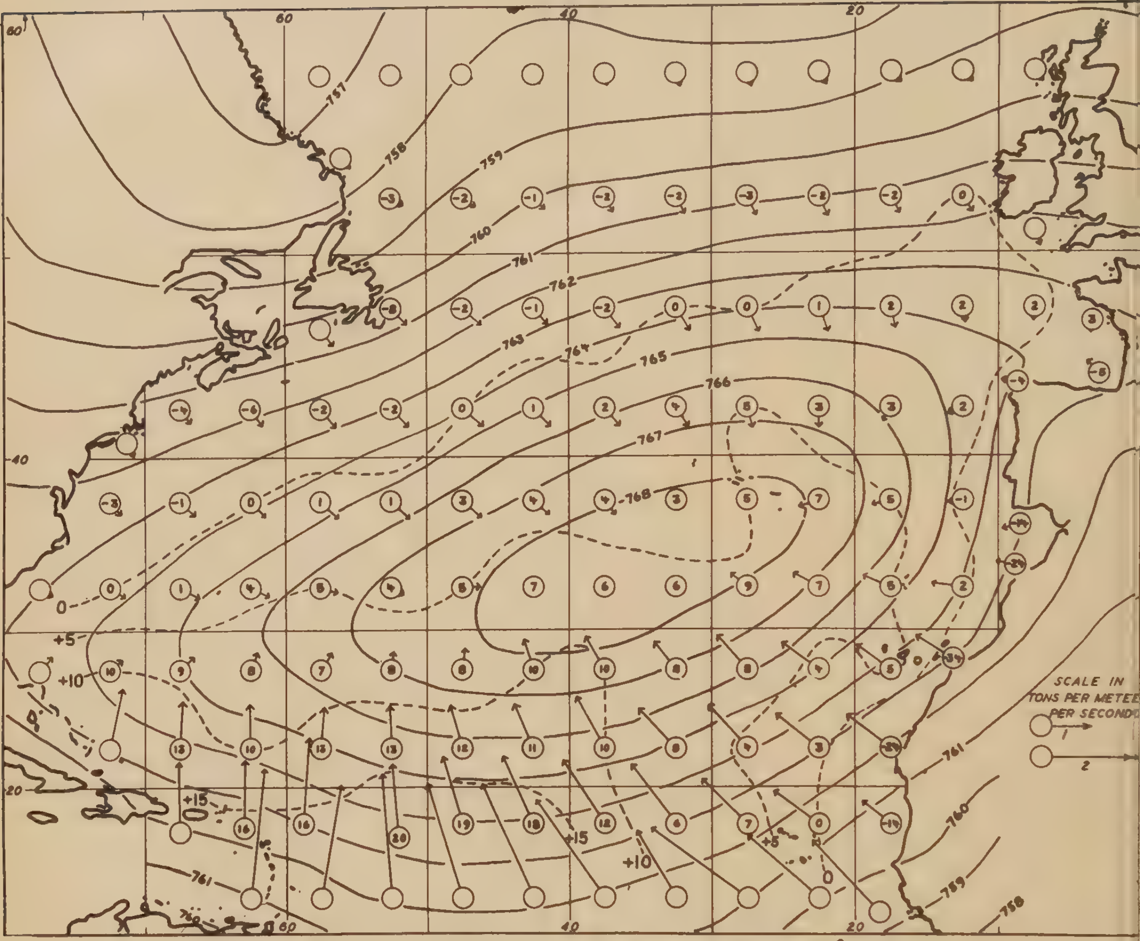

FIG. 1—SEA-LEVEL ISOBARS FOR JULY IN MM REDUCED TO LATITUDE 45°
[ARROWS SHOW TRANSPORT OF DRIFT-CURRENT IN METRIC TONS PER METER PER SECOND; NUMBERS IN CIRCLES ARE CONVERGENCE OF DRIFT-CURRENT IN CM PER DAY; BROKEN LINES ARE LINES OF EQUAL CONVERGENCE]

localities sets up pressure-gradients which result in gradient-currents. These would extend, in a homogeneous ocean, from surface to bottom, and there the bottom-currents would be superposed. We limit ourselves to the drift-current, which is the current contained in the surface frictional layer after the gradient-current has been subtracted.

Isolating this drift-current and treating it as a whole, it is seen that no friction is exerted on its lower boundary, and that the only forces acting on it are the wind-stress at the surface and the fictitious deflecting force. If the current has no acceleration, as we assume, then these forces must be equal and opposite; expressed for unit-area of the ocean this gives

$$\tau_0 = f\,T$$

where τ_0 = wind-stress, $f = 2\Omega \sin L$ = Coriolis' parameter, and T = transport of water in terms of mass per unit-time, per unit horizontal length normal to mean motion. The deflecting force acts $\pi/2$ cum sole from the mean motion, so the mean motion must be $\pi/2$ cum sole from the wind-stress.

The wind-stress in terms of the surface-wind is usually expressed by means of the non-dimensional constant γ, which depends on the height (z) at which the wind is measured and on the roughness of the surface, thus

$$\tau_0 = \rho\,\gamma^2\,W^2$$

From theoretical considerations Rossby [see 1 of "References" at end of paper] has concluded that γ depends on z, and on a certain roughness parameter z_0, in the following manner

$$\gamma = k_0/\ln[(z + z_0)/z_0] \qquad k_0 = 0.38$$

This relation seems to be verified by experience for steady winds greater than about three to five meters per second. Below this critical wind speed γ probably drops to about one-half, but above this speed z_0 and γ seem to be remarkably constant. The determinations of z_0 given in Table 1 have been made by Rossby [2] on the basis of the available observations.

Table 1

Source of data	Method	z_0 in cm	U_g in mps
Ekman	Storage of water	0.75	about 20
Wüst	Velocity-gradient near surface	0.6	about 10
Jeffreys	Angle between surface-wind and gradient-wind	0.70	10.25
		0.49	15.25
		0.32	about 22
Jeffreys	Ratio between surface-wind and gradient-wind	0.85	10.25
		0.36	15.25
		0.64	about 22

Remembering that γ changes slowly with z_0, these values are remarkably uniform. The only other indications of the values of γ and z_0 are that by Sutcliffe which is much smaller, and that by Sverdrup which is much larger. The values from these latter authors are less reliable than those from Wüst and Jeffreys, so it is justifiable to use $z_0 = 0.6$ cm for steady, moderate and strong winds, consistent with Table 1 above. Due to the uncertainty of the value of the critical wind-speed, I have used $z_0 = 0.6$ cm also for light winds, bearing in mind that the resulting estimates of the drift are probably too large.

In the present case the wind-system employed is that of the gradient-wind computed from the mean pressure-distribution for the month of July. I have used Defant's [3] mean pressures, which are given for the intersections of each five degrees of latitude and longitude. His pressures are the means of the pressures read off at the five-degree intersections by interpolation from the isobars on daily synoptic maps for the period 1881 to 1905.

The direction and magnitude of the surface-stress have been computed by means of theoretical relations derived from similarity considerations by Rossby [1]. If φ_s is the angle between the gradient-wind and the surface-wind (or surface-stress), U_g is the gradient wind-speed, and k is a universal constant which has been found to be about 0.065, then

$$N \equiv U_g/f\ z_0 = [2\sqrt{2}\ k_0/9\ k^3 \sin\varphi_s]\ e^{[2k_0(\cot\varphi_s - \sqrt{0.5})/3k]}$$

and

$$\tau_0 = (9k^2/4)\,\rho\, U_g^2 \sin^2\varphi_s$$

By means of the first of these equations φ_s may be computed from N, and from the second the net transport of the drift-current is found

$$T = (9k^2/4)\ (\rho/f)\ U_g^2 \sin^2\varphi_s$$

It is impossible to give nere even a brief summary of Rossby's theory. Its general significance may be indicated, however, by stating the distribution of eddy-viscosity which it implies. In the original theories by Ekman and by Taylor for the distribution of wind within the layer of frictional influence, eddy-viscosity was assumed to be constant in the vertical direction. This nas been extended by various authors to the case of an eddy-viscosity varying according to simple power laws, but the absolute value remains arbitrary. Rossby's theory, however, definitely defines the eddy-viscosity distribution in terms of the external parameters. He divides the region of frictional influence into two layers, a surface-layer of thickness H and an upper layer of thickness h. It is found that H = 0.12 h. At the surface the eddy-viscosity has a finite value of $\rho\ k_0\ z_0\sqrt{\tau_0/\rho}$. It increases linearly within the layer H, where the stress is assumed constant, according to

$$\eta = \rho\ k_0\ (z + z_0)\sqrt{\tau_0/\rho}$$

reaching at the top of the layer a maximum value of

$$\eta_{max} = \rho k_0 H\sqrt{\tau_0/\rho} = \rho f h^2/3\sqrt{2} = (27k^4/4\sqrt{2})\ (\rho U_g^2/f)\ \sin^2 \varphi_s$$

Within the layer h the stress decreases upward since the volume-forces (pressure-gradient and deflecting force) are taken into account, and the eddy-viscosity decreases to zero at the top according to

$$\eta = (\rho f/3\sqrt{2})\ (h + H - z)^2$$

Thus the eddy-viscosity is everywhere defined in terms of U_g, f, and z_0.

On the chart of Figure 1 are shown the pressure-distribution and, by means of arrows, the transport at the center of each five-degree square. From the transport-vectors have been computed the convergence in each five-degree square, which is indicated by the number within the circle, expressed in cm per day. Lines of equal convergence are drawn for 0, 5, 10, and 15 cm per day.

In carrying through this computation it has been necessary to make use of assumptions which may have introduced considerable error. The basic assumption is that the mean of the instantaneous transports is the same as the transport computed from the mean pressure-distribution. The correctness of this assumption becomes doubtful when we remember that the deviations from the mean (pressure-gradient, for instance) are greater than the mean itself, which may be seen by the fact that the synoptic map often shows no resemblance to the mean map. Since the gradient-wind and the pressure-gradient become quickly adjusted, and since there is a linear relation between the two, there is no reason to doubt that the mean air-movement at the gradient wind-level is given approximately by the mean pressure-distribution. But between the gradient-wind and the surface-stress there is not a linear relation. It would be possible to use as the mean surface-stress the mean computed from synoptic maps for a given period, but this lengthy computation has not yet been attempted. Further, the adjustment between surface-stress and transport of water is far from instantaneous, and, whether the time-mean of the relation between the two for the unsteady state is exactly the same as the relation for the steady state, is subject to doubt. These considerations give greater uncertainty in the region of prevailing westerlies, where the wind is more unsteady, but where, however, the transport is much less. In the trade-wind region the winds are much more steady.

In computing the surface-stress from the gradient-wind the validity of Rossby's theory has been assumed. This is unquestionably the most useful theory for work of this kind that has appeared, but the full extent to which its applicability extends has not yet been verified by experience. It must also be borne in mind that these equations represent conditions in an adiabatic atmosphere; if there is stratification within the normal height of frictional influence, the actual surface-stress is less than the computed one. Furthermore, the value of the constant k is not known accurately, or that of z_0 as mentioned above.

A difficult question always arises when calculations of this kind are carried near the equator. At a distance from the equator the sum of forces due to pressure-gradient, friction, and deflecting force is zero for the steady state. In computing transport of water (or gradient-wind) we assume no shearing stress on the bottom of the drift-current (complete absence of shearing stress). On nearing the equator with a finite surface-stress (pressure-gradient) the transport (gradient-wind) becomes larger and larger. At the equator itself there is no deflecting force, so here there must be a shearing stress at the bottom of the current to balance a finite surface stress. [Another possibility would be that the surface-stress is balanced by accelerations, but, since the whole drift-current is essentially a frictional phenomenon, this seems much less likely.] Obviously, then, this shearing stress must also be effective over a finite region near the equator. But how far from the equator does this effect extend? In particular, does it extend as far as the calculations of transport at 12°5 north?

The theoretical depth of the drift-current becomes rapidly deeper on approaching the equator. It seems reasonable to assume that the shearing stress at the bottom of the current becomes important where this depth becomes unreasonably great. At 12°5 the computed gradient-wind is about 9 meters per second, so the surface-stress may be found from $N = U_g/f\ z_0 = 4.8 \times 10^7$, $\varphi_s = 16°6$, and $\sqrt{\tau_0/\rho} = (3/2)\ k\ U_g \sin \varphi_s = 25$. The major part of the depth of the drift-current is [1]

$$h = (3k/f)\sqrt{\tau_0/\rho_w} = (3k/f)\sqrt{\rho/\rho_w}\sqrt{\tau_0/\rho} = 5300 \text{ cm} = 53 \text{ meters}$$

This is a reasonable value, and throws no doubt on the values of transport found at this latitude.

Although these considerations indicate that the calculated values of the transport should not be relied upon in too great detail, it is reasonable to assume that the order of magnitude is correct. The values of convergence depend on differences of transport; but here again the total over a large region should be of the correct order of magnitude, though the position of the maximum convergence may easily be shifted somewhat.

Unfortunately it would be very difficult to verify the computed values of transport by direct observation, since the drift-current is superimposed on other currents which are often much stronger. It would, however, be possible to obtain observations which would check some of the steps necessary in making the computation. For instance, the surface-stress in terms of the surface-wind could be studied very nicely from further observations of the wind-gradient within the 10 or 20 meters directly above the ocean-surface.

It is not my purpose to discuss here the significance of the results obtained, but there are a few remarks which should be made.

If we add all the convergences within the region bounded by the line of zero-convergence and by 20° north, we get 9.7 million tons per second. Or, if we add to this the 3.9 found between 15° and 20°, which is more doubtful, we get 13.6 million tons per second.

The total northward transport across the parallel of 15° north between Africa and 65° west is found to be 8.9 million tons per second, and that across 20° north between Africa and 70° west is 5.97 million tons per second.

The divergence from the African coast is roughly the outward transport across the following line: Starting from off the Portuguese coast at 40° north and 10° west, south to 30° north, west to 15° west, south to 25° north, west to 20° west, south to 15° north, and finally east to the African coast; the net transport is 1.8 million tons per second.

In order to obtain an idea of the significance of the order of magnitude of these quantities, they may be compared with the transport of the Gulf Stream off Cape Hatteras, which is normally between 80 and 90 million tons per second.

Perhaps the most striking consequence of this study is that the region of maximum convergence is not within the Azores high-pressure area, but is some distance to the southwest. In fact, according to this calculation it is displaced more than a thousand miles. Unfortunately its exact location, even according to the methods here used, cannot be given because Defant's pressure-values extend southward to only 10° north.

This brings up a matter which I would like to emphasize. To my knowledge, these values from Defant are the only ones of a similar character which cover a large ocean-region. The very elaborate atlases of the Koninklijk Nederlandsch-Meteorologisch Instituut give, for each degree square, the mean of pressures observed by ships within that square for each of the twelve months. For a study of this kind they turn out to be of very little value. If studies of this kind should prove to be of value, it will be indispensable to have available detailed mean values of pressure and wind-roses over as much of the ocean-regions as possible, which have been obtained by interpolation from synoptic maps, such as those of Defant and Clayton [4]. If this type of study should have any bearing on the field of long-range weather-forecasting, then mean values should also be available for short periods, such as individual months. For North America, it would seem that the Pacific Ocean would be fully as important as the Atlantic.

Note: This computation is presented in greater detail in the paper by R. B. Montgomery on Transport of surface-water due to the wind-system over the North Atlantic, published in Papers in Physical Oceanography and Meteorology, v. 4, No. 3, 1936.

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Contribution No. 106

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CORRELATIVE STUDIES OF MICROSCOPIC AND PLATE METHODS FOR EVALUATING THE BACTERIAL POPULATION OF THE SEA[1]

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An estimation of the abundance of marine bacteria offers technical difficulties because many of the organisms cannot be cultivated readily by the usual methods. Discouraged by the small numbers of bacteria found by the common plating methods, direct microscopic counts have been attempted by several investigators. A direct and accurate estimation of the bacterial population has not been possible even by these methods, the various concentration procedures seeming to increase the sources of error and the difficulties of technique. Recently Henrici (1933) has introduced a method for studying water bacteria by suspending slides in aquaria and then observing microscopically the forms which became attached; this method was later extended to the study of bacteria in natural bodies of water (1935). ZoBell has applied the method to the study of marine bacteria (1935). The method was not utilized for a quantitative study of the organisms and these workers questioned the feasibility of such a procedure.

Our original plan, to investigate the marine bacteria in the vicinity of Woods Hole by this direct method, was frustrated by the turbulence of the waters with their heavy suspensions of organic and inorganic particles. On slides suspended in sea water under laboratory conditions for varying time intervals a variation in the number of attaching bacterial cells was observed; a technique was evolved for making a quantitative count by this method, and it has been possible to establish a relation between such a determination and the numbers obtained by the plate method. In spite of the many errors in sampling and dilution, the plate method seems still the simplest method that is now available, especially since results of different workers in different localities can be reproduced.

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[1] Contribution No. 106 of the Woods Hole Oceanographic Institution; contribution from New York Medical College and Flower Hospital, and Journal Series Paper of the New Jersey Agricutural Experiment Station.

The experiments of Waksman and Carey (1935, a and b) on the rate of bacterial multiplication in resting water have been repeated, using, for comparative purposes, the plate method, the direct microscopic method, and the new method which can be called the "attachment count." The technique used in the plate count has been described in previous publications (Reuszer, 1933; Waksman, 1934). For the direct microscopic count a modification of the method of Winogradsky (Waksman, 1932) was used.

In the "attachment count" method, glass microscope slides were boiled in soap and water, rinsed and immersed in chromic acid cleaning solution, again rinsed thoroughly in distilled water and placed in ethyl alcohol. Before use, the slides were passed through a flame and the alcohol allowed to burn off. The cleaned slides were then suspended for twenty-four hours in the solution to be tested. On removal, the slides were allowed to dry in a level position, fixed with methyl alcohol or heat, and stained with carbol-erythrosin. (Staining may be accomplished after a few minutes over a steam bath or in cold solution after one hour.) The slides were washed gently but thoroughly, so that no small needle-like crystals would complicate the microscopic picture. The excess moisture may be drained off, but the film is not to be blotted. The area to be counted was standardized with a micrometer eye-piece. For these experiments, a microscope field with an estimated area of 0.0066 sq. mm. was used. For counting, an oil immersion lens and a No. 10 ocular were employed. If the cells tended to have an even distribution on the slide, ten fields were counted; when the distribution was uneven a greater number of fields was examined. The counts were averaged to represent the total number of cells in 0.066 sq. mm. of surface.

The values obtained by the three methods were taken from experiments designed to show, (a) the influence of temperature upon the attachment of bacteria to slides, (b) the influence of the addition of nutrient material upon the attachment of bacteria to slides, (c) the attachment of pure cultures of marine bacteria, and (d) the influence of filtration and light. A series of counts was also made on samples of sea water obtained weekly at two stations.

Statistical methods were used in an attempt to analyze the values obtained. In table 1, the data obtained by the plate count method have been compared with the values obtained by the attachment method. The subject, designated by (*s*), consisted of a series of eight groups representing numbers from 0 to 500,000,000, and represented the bacteria per cubic centimeter estimated by the plate method. The relative, designated by (*r*), consisted of a series of eight groups representing numbers from 0 to 30,000, and indicated the bacteria per 0.066 sq. mm. estimated by the attachment method. As the figures for the plate counts were checked off entries were made in the corresponding square in the attachment count. Hence, reading left to right in the upper line where the plate count was between 0 and 100, it is seen that four times the attachment count was in the group 0 to 75, five times in the group 76 to 250, once in the group 499 to 1000, and once in the group 999 to 2000. Reading left to right on

TABLE 1

Correlation between plate counts, in bacteria per cubic centimeter (s), compared with attachment counts, in cells per 0.066 sq. mm. (r)

GROUPS (*s*)	GROUPS (*r*)								
	0–75	250	500	1,000	2,000	5,000	10,000	30,000	Total
0–100	4	5		1	1				11
500	4	10	4	2					20
5,000	4	4	2		1				11
50,000	15	10	2	3	1	3			34
100,000	2	4	6	1	3				16
1,000,000	3	8	14	5	4	1	1		36
50,000,000	1	4		5	2	2	4		18
500,000,000						1	1	3	5
Total.......	33	45	28	17	12	7	6	3	151

the last line, where the plate count was 50,000,000 to 500,000,000, the attachment counts also appear in the columns indicating high figures. For a perfect direct correlation the line of squares containing numbers should slope to the right at an angle approaching 45 degrees.

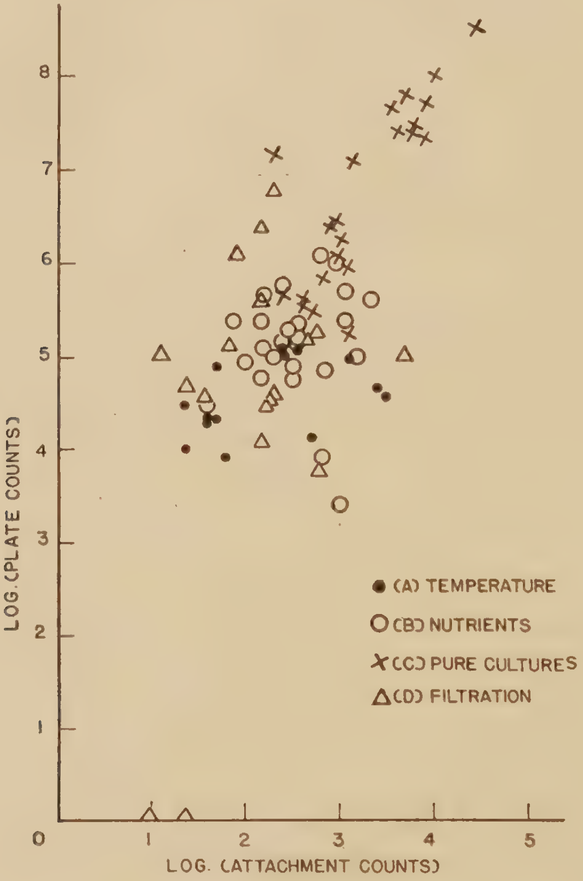

Fig. 1. Scatter Diagram. Logarithms of Plate Counts Plotted against Logarithms of Attachment Counts

Similar tables (tables 2 and 3) were prepared to estimate any relation between the values obtained by the plate method and the direct microscopic method, and the counts obtained by the two microscopic methods. All the data were used in making these tables. The tables suggest that some relationship may exist between the different values; this is more evident in the case of the attachment count than the direct microscopic count.

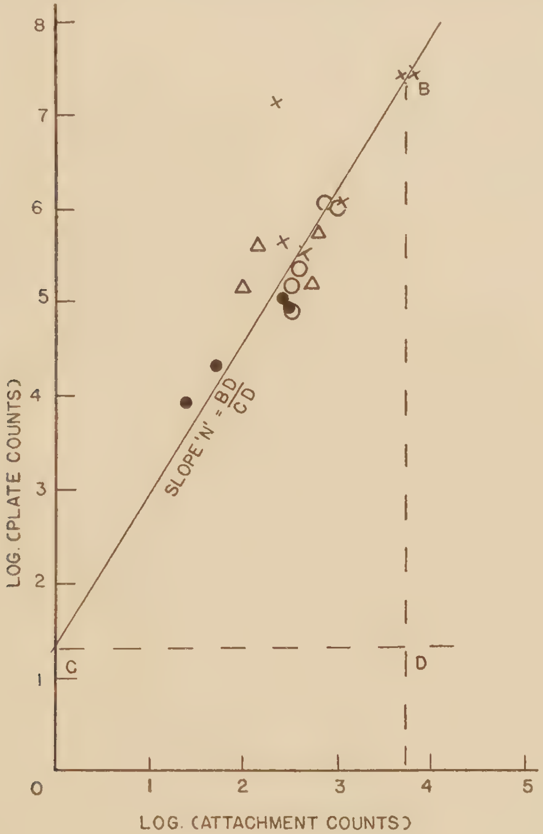

FIG. 2. LOGARITHMS OF PLATE COUNTS PLOTTED AGAINST LOGARITHMS OF ATTACHMENT COUNTS. VALUES FOR TWENTY-FOUR- AND FORTY-EIGHT-HOUR INCUBATION PERIODS

The most significant fact is the impossibility of grouping the numbers in an arithmetical series. In the scatter diagram (fig. 1), the logarithms of the plate counts (y axis) have been plotted against the logarithms of the attachment counts (x axis), and for this scatter diagram the results on resting water were used, omitting the counts from the weekly sea water samples. A study of the graph suggests that there is a linear relation between the two logarithms of the counts.

If Y represents the plate count and X the attachment count, then by plotting log Y against log X, a mean straight line can be drawn which approximately represents the relation between these two variables. Hence the relation between the two types of count must be of the form $Y = AX^n$, where n is given by the slope of the straight line and A by its intercept on the log (plate count) axis (Feldman, 1935).

In figure 2 the logarithms of the values obtained in the twenty-four- and forty-eight-hour incubation periods have been plotted and such a mean straight line drawn. The slope of the line BC may be determined from the tangent of the angle BCD, and by direct measurement it is found to be 1.5. The intercept of the line BC has a value of 1.3, hence from figure 2, log A is 1.3.

Expressed in logarithms the fundamental equation becomes: $\log Y = \log A + 1.5(\log X)$.

The value to be assigned to "A" can also be calculated by using the values for X and Y obtained experimentally. Thirteen experimental values taken from experiments a, b, and c (incubation periods one to five days) gave the following results for A:

log Y	log X	log A	A
3.973	1.397	1.879	75.7
4.330	1.672	1.822	66.4
4.982	2.477	1.268	18.6
5.079	2.392	1.491	31.0
5.096	2.394	1.505	32.0
4.929	2.536	1.125	13.4
5.380	2.588	1.498	31.5
5.193	2.488	1.461	28.9
7.478	3.826	1.739	54.9
7.439	3.639	1.982	95.9
6.096	3.048	1.524	33.4
5.567	2.612	1.649	44.6
5.670	2.424	2.034	108.0
Mean		1.687	48.7

To test the equation, there remains a substitution of the calculated values of log A (1.687) and "n" (1.5) in the formula, and a substitution of the observed value for log Y, using each experimental value found for Y. The value for log X can be calculated and a comparison with the value for X actually found can be made. The observed and calculated values are given in tables 4, 5, 6, and 7. Forty-nine of the 84 calculated values are in agreement with the observed values.

TABLE 2

Correlation between plate counts, in bacteria per cubic centimeter (s), compared with direct microscopic counts, in cells per 0.066 sq. mm. (r)

GROUPS (s)	GROUPS (r)								
	0–75	250	500	1,000	2,000	5,000	10,000	30,000	Total
0–100	7					1			8
500	13	1							14
5,000	10		1						11
50,000	15	10	2	4	1	1			33
500,000	13	18	9	3	2				45
5,000,000	10	2	2						14
50,000,000	1	1	1	1	3	1			8
500,000,000				1	2		3		6
Total.......	69	32	15	9	8	3	3		139

TABLE 3

Correlation between direct microscopic counts (s) compared with attachment counts (r), in cells per 0.066 sq. mm.

GROUPS (s)	GROUPS (r)									
	0–75	150	250	500	1,000	2,000	5,000	10,000	30,000	Total
0–75	22	11	7	10	8	2				60
150	4	2	3	3	4	1	1			18
250	3	1	4	5	2	2				17
500	2	1	1	6	1	4	1			16
1,000	2				1	3		2		8
2,000		1	1		1		3	3		9
5,000			1			1		1	1	4
10,000									2	2
30,000										
Total.....	33	16	17	24	17	13	5	6	3	134

TABLE 4

Effect of temperature on sea water cultures. Attachment count, calculated and observed

INCUBATION	2 DAYS		5 DAYS		11 DAYS		15 DAYS	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
1. Sea water 4°C.	33	25	188	248	195	354	112	174
2. 22°C. (dark)	58	47	80	3,184	157	1,359	80	52
3. 22°C. (light)	157	300	39	518	57	39	51	29
4. 30°C.	183	247	145	57	71	24	57	43

TABLE 5

Effect of added ingredients on sea water cultures. Attachment count, calculated and observed

INCUBATION	1 DAY		4 DAYS		9 DAYS		13 DAYS	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
1. Sea water	145	344	264	286	155	1,614	128	275
2. Sea water + 1 mgm. glucose	219	308	304	150	130	681	459	169
3. Water + 3 mgm. glucose	291	383	168	201	301	1,120	533	256
4. Water + 1 mgm. glucose + 0.625 mgm. $NaNO_3$	820	942	479	1,201	203	362	108	354
5. Water + 3 mgm. glucose + 1.25 mgm. $NaNO_3$	857	690	447	2,180	236	280	118	149

TABLE 6

Growth of pure cultures of marine bacteria in sea water and in sea water plus peptone. Attachment count, calculated and observed

INCUBATION	1 DAY		3 DAYS		8 DAYS		13 DAYS	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
1. Bacterium 16 (sea water)	867	1,118	1,450	872	347	553	652	1,228
2. Bacterium 22 (sea water)	386	410	555	682	449	486	231	1,273
3. Bacterium 23 (sea water)	455	266	1,520	896	4,210	1,380	1,150	1,022
4. Bacterium 16 (peptone)	4,400	208	7,250	6,290	13,000	5,766	9,780	3,275
5. Bacterium 22 (peptone)	7,020	6,702	38,600	26,000	17,300	11,508	17,300	9,200
6. Bacterium 23 (peptone)	6,830	4,362	19,800	26,000	14,000	2,261	13,900	9,300

The tables show that the mathematical agreement is best in the first three days of incubation, which represents the logarithmic stage of growth. During the next stage of growth the viable cells, represented by the plate counts, may be fewer than the cells which are visible under the microscope. Finally, in the longer incubation periods, an equilibrium is again established and shows itself in a mathematical agreement. A growth curve based on the attachment counts will be smoother than one based on petri plate counts, but the latter will be more sensitive to short time fluctuations.

TABLE 7

Effect of filtration and light on sea water cultures. Attachment count, calculated and observed

INCUBATION	2 DAYS		5 DAYS		10 DAYS		20 DAYS	
	Calculated	Observed	Calculated	Observed	Calculated	Observed	Calculated	Observed
1. Sea water (dark)	197	74	71	181	43	157	149	104
2. Sea water (light)	209	531	134	219	198	219	90	222
3. Sand filtered (dark)	508	519	78	191	184	5,440	167	13
4. Sand filtered (light)	426	139	90	38	114	702	97	25
5. Seitz filtered (dark)	0	26	0	0	2,466	208	1,480	157
6. Seitz filtered (light)	0	10	7	0	871	99	151	270

In cultures containing many millions of cells per cubic centimeter the attachment count may become less accurate due to the difficulty in counting the microscopic field. Small cells are difficult to count and may cause discrepancies. Where concentrations of bacteria are low, and no variable which changes cell viability with rapidity has been introduced, the values reached by the two methods are comparable. (Such a variable might be a disinfectant which killed but did not disintegrate the cells.)

Conversely, if with adequate determinations, no mathematical agreement can be reached by the two methods, an effort should be made to detect some unrecognized factor which is influencing the growth of the cells.

In clear waters, where preparations may be made by suspending slides directly, it should be possible to obtain comparable values; but when samples must be taken and kept in the laboratory for the twenty-four-hour period a second plate count is necessary so that an interpolation may be made to determine the number of viable cells originally present.

SUMMARY

Bacterial numbers may be estimated by the immersion of slides in water, with a slight modification of Henrici's original technique. In contrast to other microscopic methods, this method, designated as the attachment count, can be utilized in the case of waters containing small numbers of bacteria.

Not only were high values for the plate counts associated with high values for the attachment counts; but constants could be determined from experimental data which permitted the calculation of the numbers to be expected from the attachment count, if the plate counts were known.

The correlation between the values obtained by the two methods was noted in a study of a series of growth curves obtained by using, (a) sea water samples kept at different temperatures, (b) sea water samples to which a source of carbon or a source of carbon and nitrogen in combination was added, (c) pure cultures of marine bacteria growing in sterile sea water or in sea water enriched with peptone, (d) filtered sea water.

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THE BIOLOGY OF OITHONA SIMILIS IN THE GULF OF MAINE AND BAY OF FUNDY

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Introduction

Although *Oithona similis,* one of the two microcalanids found breeding in the Gulf of Maine, is small in size, the relative abundance of larvæ indicates that at times it forms a significant factor in the natural economy of the region.[2] It is also particularly favorable for quantitative study because adults, larvæ, and egg cases all appear to be sampled representatively with fine nets (No. 10 silk) and the pump.

This paper forms the third of a series on the biology of zoöplankton species in the Gulf of Maine and Bay of Fundy with special reference to production and dispersal, and is based on material obtained between July 28, 1931 and September 29, 1932, in the course of investigations carried on for the International Passamaquoddy Fisheries Commission. For a description of the area covered, location of stations, and methods, the reader is referred to a previous report (Fish, 1936*a*).

Regional Distribution of the Adult Stock

Oithona similis is almost "world wide" in distribution (Bigelow, 1926), but on the American coast appears to be largely centered north of Cape Cod. South from this point it is gradually replaced, in neritic waters at least, by *O. brevicornis,* a species not yet reported north of the Cape. At Woods Hole in 1922 and 1923 (Fish, 1925, Fig. 47) the latter species occurred with southern forms during the summer from late June to mid-October, and *O. similis* with the boreal population in autumn and winter. Farther south in Chesapeake Bay *O. similis* is decidedly a winter form limited largely to the inner Bay and is exceeded by *O, brevicornis,* which occurs everywhere in that region throughout the year (Wilson, 1932).

North of Cape Cod McMurrich (unpublished data) found *O. similis* in small numbers in Passamaquoddy Bay regularly during the colder months from November until March, but very rarely during the spring and summer. Elsewhere in Canadian waters, however, it has been reported widespread offshore during the summer (Herdman, Thompson, and Scott, 1898; T. Scott, 1905; Pinhey, 1926).

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[1] Contribution No. 109.

[2] *Microsetella norvegica,* the second species, is far less important numerically.

In 1931–32 *O. similis* was taken to some extent throughout the Gulf of Maine and Bay of Fundy, the most noticeable changes in the quantitative distribution of the adult stock occurring with the vernal warming of the water. In April, 1932 it was most numerous (up to 5,423 per minute) in the western area of the Gulf with smaller and apparently more local centers of abundance in the Middle Channel, off Yarmouth, and off Halifax. In the outer basin of the Gulf it was almost totally absent in the hauls (Fig. 1).

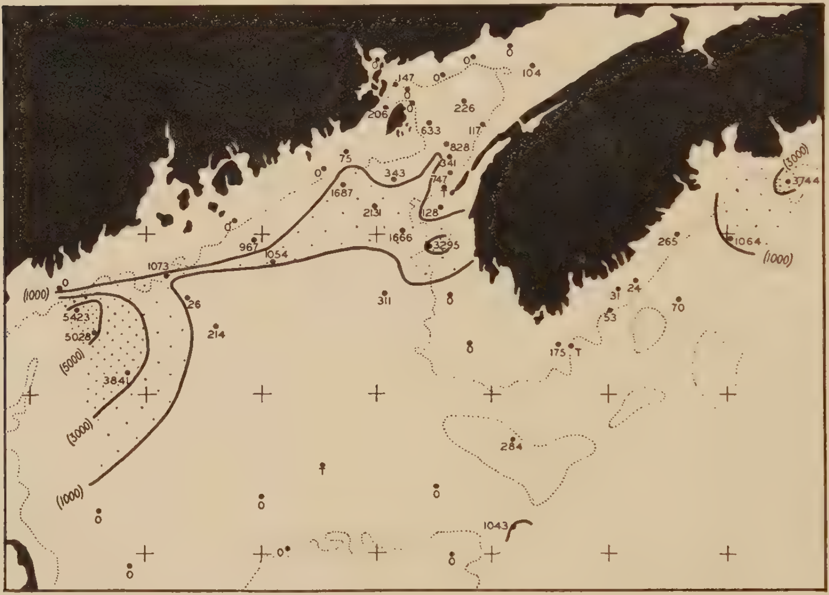

FIG. 1. Distribution of adults of *Oithona similis* in April, 1932. Number per minute of towing.

The changes in distribution from April to May would suggest that *Oithona* tends to withdraw into deeper water in winter, and approaches the coast with rising temperatures in the spring. By the end of May the greatest number of adults (6,087 per minute) was found at the innermost station off Casco Bay where the surface temperature was 8.63° C., although they were abundant throughout the western area (6.08°–9.38° C.) and in the Bay of Fundy along the course of the entering drift. The richest hauls at this time were everywhere obtained at temperatures exceeding 6° C. *Oithona* was still sparse in the colder waters of the upper Bay, the Quoddy region, and thence westward along the coast of Maine to Frenchmans Bay.

There was a marked increase in the adult stock between May and June but no appreciable changes in distribution. Again the richest hauls were made nearest Casco Bay, and the poorest in the New Brunswick and eastern Maine coastal areas. The adult stock reached its peak at this time in the western Gulf and, although the subsequent crop yielded larger numbers of larvæ in August (Table IV), few apparently reached maturity. East of Mt. Desert adults did not reach their peak until August and the maximum was of short duration for, in the Bay of Fundy at least, they had almost reached the April level by mid-September.

PRODUCTION AND DISPERSAL OF EGGS AND LARVÆ

Spawning Areas

Spawning is widespread but varies greatly in different parts of the region. Until July, in 1932, with the major portion of the *Oithona similis* population located in the western part of the Gulf, the rapid decline to the eastward resembled that of *Calanus finmarchicus* (Fish, 1936*a,* Fig. 11). Only in the outer part of the Bay of Fundy was there a slight break in the descending curve, and here the greatest increase was in copepodite stages, probably transported for some distance from the western or outer Gulf (Fig. 3). This is indicated by the low values in the sections from the inner Bay (*F* and *G*) and in the path of the drift from the Bay along the coast as far west as Mt. Desert (*E*).

The eastern region assumed greater importance in midsummer, and the curve for August (Fig. 3) more closely resembles that of *Pseudocalanus* (Fish, 1936*b,* Fig. 1) than *Calanus.* Extensive spawning continued in the western area, but the large numbers of early and late nauplii entering the Bay of Fundy and eastern Gulf at this time are indicative of important propagation nearby. Early nauplii, up to 19,258 per cubic meter, in the Bay could hardly have originated beyond the eastern basin. This is also evident from the number of early larvæ at all offshore stations east of Penobscot Bay in the Gulf (Fig. 9*C*).

The Bay of Fundy itself, however, appears to be a relatively unimportant spawning area. In the Quoddy region beyond the immediate influence of the drift from the Gulf, no eggs were found before July 30, and at all times both eggs and early stages were comparatively sparse, a condition also prevailing eastward along the New Brunswick coast and at the innermost stations (9, 10*A* and 11*A*). Elsewhere in the

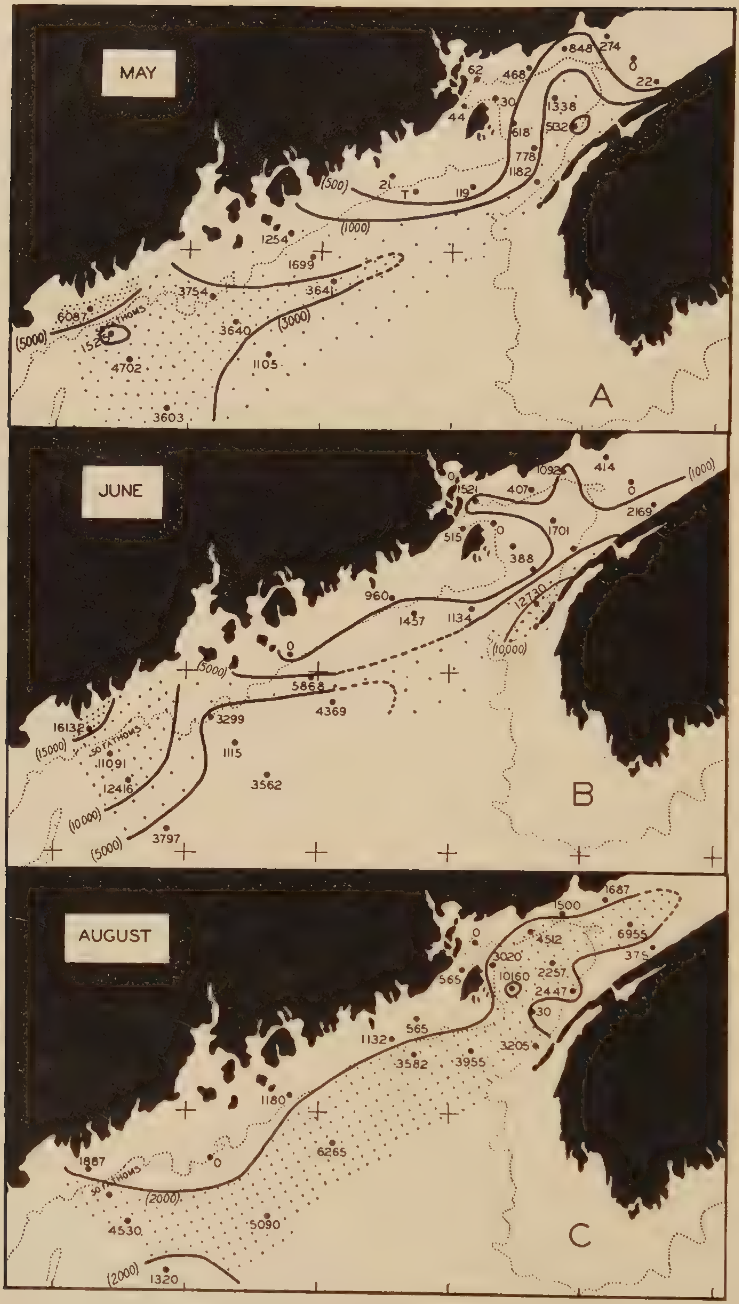

FIG. 2. Distribution of adults of *Oithona similis* in 1932. May–June: number per minute. August: number per cubic meter.

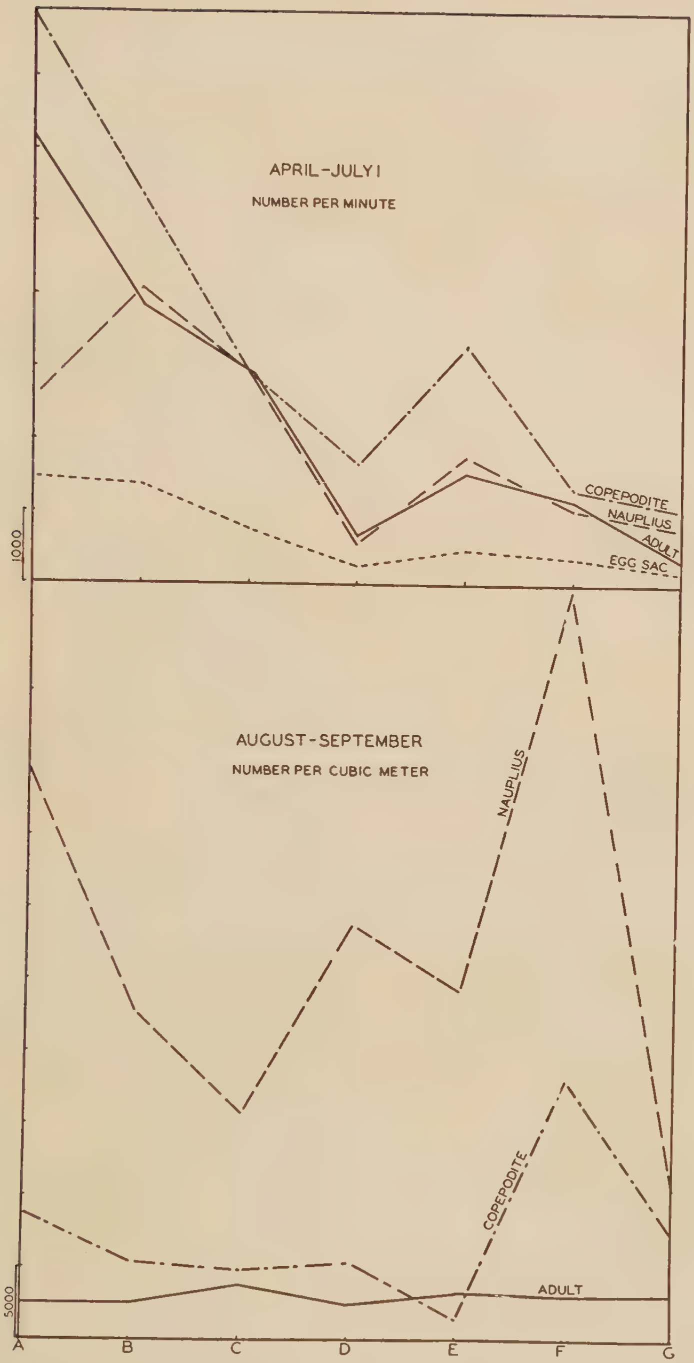

FIG. 3. Mean numbers of adults and young of *O. similis* in seven sections between Casco Bay and Cape Spencer in 1932. Sections: *A*. Casco Bay (Stations 23*A*–25*A*, 26); *B*. Penobscot Bay (Stations 27–29); *C*. Mt. Desert (Stations 17, 30–31); *D*. Moose Peak (Stations 32–33); *E*. Passamaquoddy Bay (Stations 5–8*A*, 35); *F*. Pt. Lipreau (Stations 13, 36–37); *G*. Cape Spencer (Stations 9–11).

Bay they were frequently very abundant, with hauls in August yielding up to 35,970 early nauplii per cubic meter (Fig. 9*C*), but these were always in the path of the entering drift.

Breeding Seasons

Like the other dominant boreal copepods, *Calanus finmarchicus* and *Pseudocalanus minutus, Oithona* begins spawning in the Gulf of Maine in March and continues in a succession of generations until September. There is a seasonal delay of about one month in the appearance of eggs in the eastern Gulf and Bay of Fundy and this regional variation permits the distinguishing of two breeding stocks, a western and an eastern. Also, as in the case of the two above-mentioned species it must be borne in mind that these stocks of *Oithona* are not permanently restricted to their respective localities, but merely represent delayed maturation of that portion of the winter population which happens to be located in the eastern part of the region during the spring, and earlier maturation in areas to the westward where the water mass responds more rapidly to vernal warming. However, since the augmentation starts at significantly different times in the two regions, with substantially the same interval of development, subsequent broods of the two stocks continue to appear at distinct periods irrespective of where they are dispersed.

Annual Cycle in the Two Breeding Stocks

Very little has been published on the biology of this species. Gran (1902) found some indication that the development of small species like *Oithona similis, Microsetella atlantica* and *Oncæa conifera* is completed in a much shorter time than in larger species like *Calanus finmarchicus, C. hyperboreas, Metridia longa,* and *Euchæta norvegica.*

Ruud (1929) reported that the stock of *O. helgolandica* (*similis*) doubled in number off More in 1925 from the end of May to the end of July. In 1926 a small stock at the beginning of March increased steadily until May 12. A second increase took place later, reaching a maximum on July 20. In 1927 conditions were similar except that the second maximum attained the highest peak of the year on July 31. Bogorov (1932) found copepodite stages III and IV predominating in the Barent's Sea at the end of July.

In the Gulf of Maine and Bay of Fundy the maxima of different larval stages, following the appearance of the first brood of the stock maturing in the western Gulf in March, indicate a developmental period throughout the region of about two months during the early season, and about six weeks in summer.

There appear to be at least three and possibly four broods of the western stock in March, May, July, and September. This stock, which in 1932 was represented by a maximum of late nauplius and copepodite

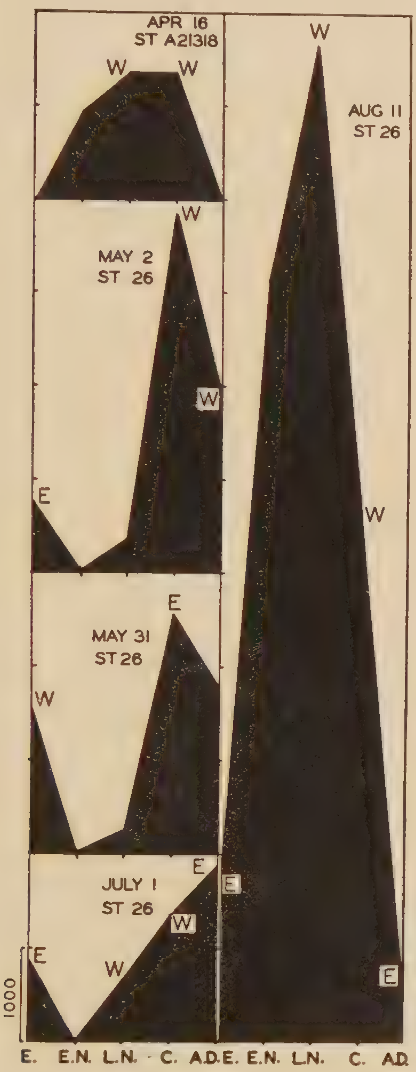

FIG. 4.

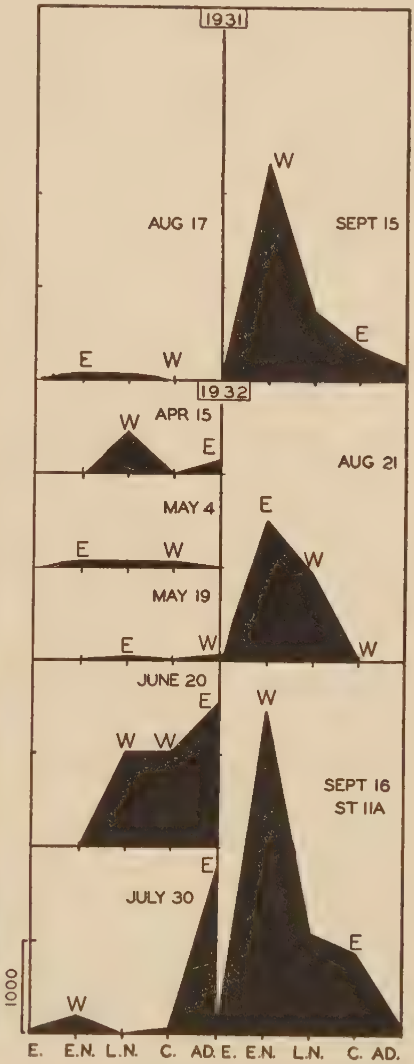

FIG. 5.

FIG. 4. Composition of the population of *Oithona similis* in the outer part of the western area in 1932, showing the succession of generations of the western (*W*) and eastern (*E*) stocks. April–June: number per minute. August–September: number per cubic meter. Stages recorded as *E*-egg sacs, *E.N.*—early nauplius (I–III), *L.N.*—late nauplius (IV–VI), *C.*—copepodites (I–V), *A.D.*—adults.

FIG. 5. Composition of the population of *Oithona similis* at Station 5 in the New Brunswick area of the Bay of Fundy in 1931 and 1932. Symbols as in Fig. 4.

stages on April 16, had by May 2 advanced largely to late copepodite stages and by May 31 matured and was spawning (Fig. 4). The second brood had reached late nauplius-copepodite stages by the end of June. The third brood, apparently developing more rapidly, was dominated by late nauplii in mid-August and what appeared to be a fourth brood was in egg and early nauplius stages on September 15–16 (Fig. 5).

There are three broods indicated in the eastern stock. Eggs found between April 20–May 2 had presumably advanced to copepodite stages by the end of May (Fig. 4). A second brood of eggs appeared a month later, and a third brood by mid-August. That portion of the stock remaining on September 15–16 in the Bay was apparently represented by late nauplius and early copepodite stages.

Table I

Dominant stages of the eastern and western stocks of P. minutus and O. similis occurring at comparable periods in 1932.

1932	Western Stock		Eastern Stock	
	P. minutus	O. similis	P. minutus	O. similis
April 16........	Late nauplius	Late nauplius-copepodite	Egg	Egg
May 19–22.....	Late copepodite	Adult	Late nauplius	Late nauplius
May 31........	Adult	Egg	Late nauplius-early copepodite	Copepodite
June 20–31.....	Late nauplius	Late nauplius-copepodite	Egg	Adult-egg
July 30........	Egg—early nauplius	Early nauplius	Adult	Adult
August 11......	Late nauplius	Late nauplius-copepodite	Adult-egg	Adult-egg
September 15–16	Egg	Egg—early nauplius	Late nauplius	Late nauplius-copepodite

The successive generations of the two breeding stocks of *Oithona* as shown in Table I and in Figs. 4 and 5 compare very closely with those of *Pseudocalanus* (Fish, 1936*b*, Figs. 2–4).

It will be noted that in the western stock *Oithona* in 1932 appeared to be slightly more advanced than *Pseudocalanus* at comparable periods throughout the summer, while in the eastern stock very little difference was detectable.

Productivity and Mortality in Developing Larvæ

Oithona similis was frequently taken during the breeding periods with one or two attached ovisacs. However, by far the larger number was found floating free in the water. Whether or not the sac normally remains attached to the female for only a short period of time to insure fertilization, and then becomes detached to permit the formation of others, is not known. It is, of course, possible that those in the samples were broken off in the process of capture, but considering the large number of larvæ produced by a relatively small parent stock in August, several sacs of eggs must have been produced by each female at that season. Unlike *Pseudocalanus,* where the ovisac was never found around detached eggs, the ovisac of *Oithona* remains intact during the period of incubation and no doubt serves to protect the eggs from small predatory forms until they have hatched, a condition also found in *Microsetella.*

From April until the end of June in 1932 the stock of *Oithona* increased as shown in Table II, but considering the relative number of adults and young, it does not appear to have been an unusually prolific species during this period. In midsummer, however, with the maturing of the second western brood, a third crop of larvæ appeared, outnumbering the combined young of all other species of copepods both in 1931 and 1932 (Tables II and IV). It is not possible to say whether the parent stock of the third eastern brood is equally productive, because spawning had just started at the time of the last cruise in the Gulf, in mid-August.

TABLE II

Mean numbers of larvæ and adults of Oithona similis in the total region. April–June: number per minute. August–September: number per cubic meter.

	Month	Larvæ	Adults
1932	April	1,112	879
	May	5,918	2,519
	June	8,919	3,387
	August	34,852	2,938
	September	3,262	332
1931	August	33,925	3,550
	September	4,825	94

Like *Pseudocalanus,* the greatest mortality in developing larvæ of *Oithona* seems to take place in the nauplius stages. This can be seen by comparing the abundance of nauplii in August with that of copepodites and adults in September (Fig. 9 and Table II). In the Bay of Fundy, where the mean number of late nauplius and copepodite stages in August amounted to 26,655 per cubic meter, September collections showed a decline to 1,720 late larvæ and 332 adults per cubic meter. A similar decline was also found in September, 1931.

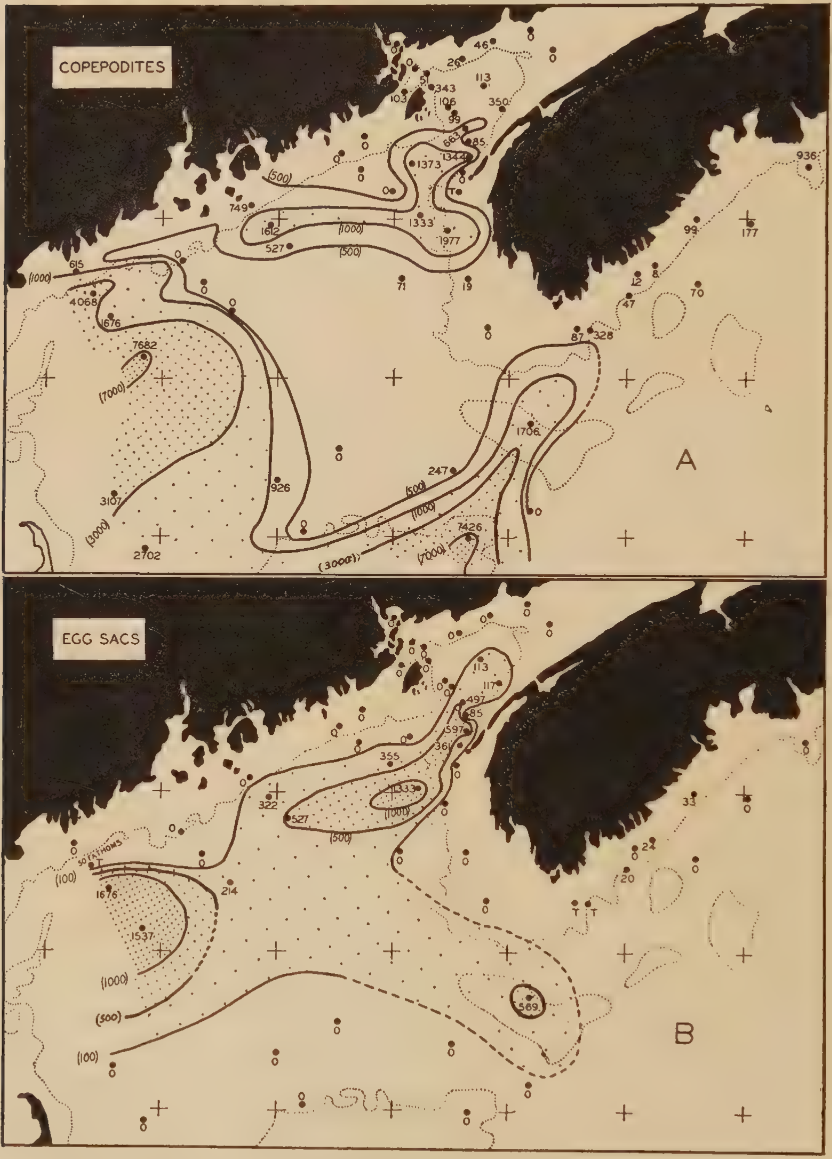

FIG. 6. Occurrence of copepodite stages of the western stock and egg sacs of the eastern stock in April, 1932. Number per minute of towing.

Dispersal and Regional Abundance of Eggs and Larvæ

Dispersal in 1932.—The method of tracing dispersal by monthly changes in the distribution of developmental stages of the different breeding stocks has been used in the present analyses. The general surface circulation and expected drift of eggs and larvæ within the Gulf and Bay of Fundy has previously been described (Fish, 1936*b*).

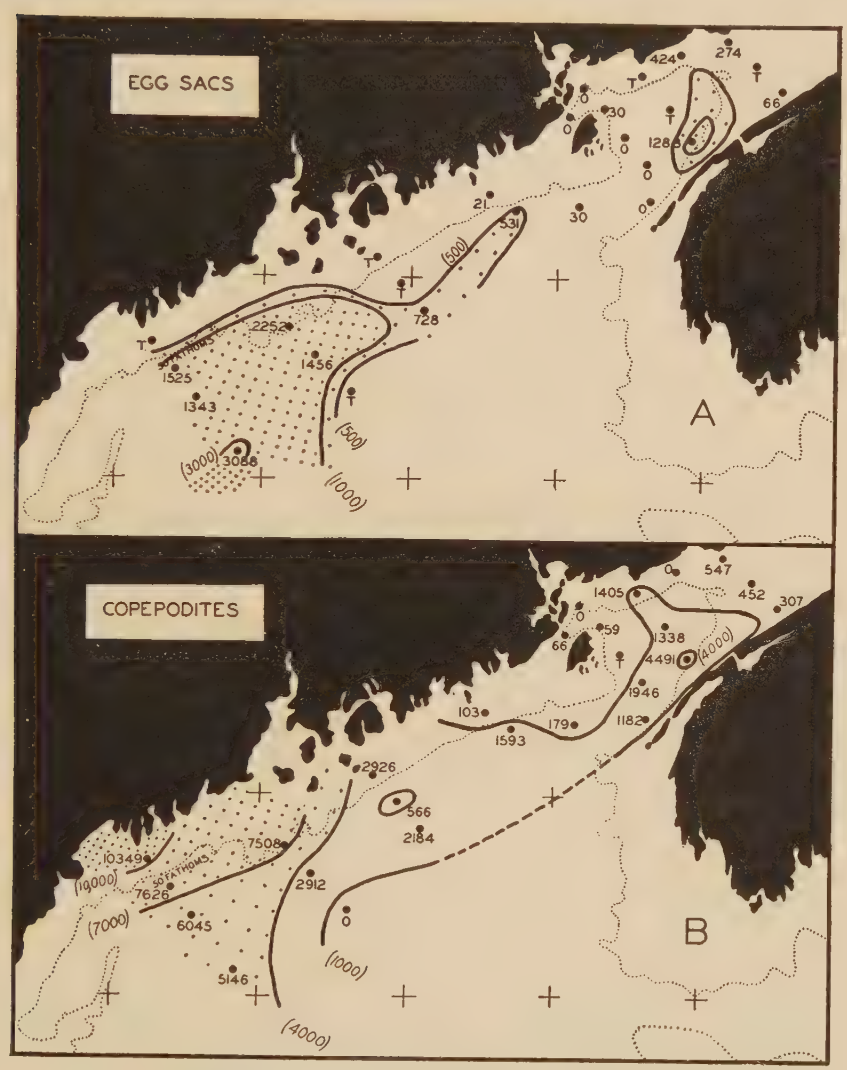

FIG. 7. Occurrence of egg sacs representing the second brood of the western stock and copepodite stages of the first brood of the eastern stock in May, 1932. Number per minute of towing.

In the case of *O. similis* there was an apparent difference in the general distribution of larvæ of the two breeding stocks. Spawning of the western stock began seaward of the 100-meter contour and subsequent generations remained for the most part concentrated offshore. The eastern stock, on the other hand, although emanating largely from the eastern basin, soon became widely dispersed in the coastal zone, and succeeding broods, particularly in the more advanced larval stages (Fig. 7*B*), were until August at times more abundant inside than outside of the 100-meter contour.

Western Stock.—Spawning offshore in the western basin and in the region of Georges Bank in March, by April 16 (Fig. 6*A*) larvæ in late nauplius and copepodite stages were found most abundant in the offing of Casco Bay and seaward in an arc corresponding with the general surface drift to the outer banks. Smaller numbers occurred in the eastern basin, the Bay of Fundy and along the south coast of Nova Scotia. Like *Calanus* and *Pseudocalanus,* in outer waters *Oithona similis* appears to reproduce off Halifax as early as in the western basin of the Gulf.

This brood remained centered in the western area, although by late May when the stock had matured and was spawning (Figs. 2*A* and 7*A*), a considerable number, having presumably circled the outer Gulf, were found entering the Bay of Fundy along the Nova Scotian side. The largest single haul of adults (possibly eastern stock; see p. 181) was made at the innermost station off Casco Bay, but egg sacs were for the most part concentrated offshore westward from Mt. Desert.

The second brood greatly increased the size of the western stock and by the end of June had become generally distributed offshore in the Gulf. The larvæ, at this time in late nauplius and copepodite stages (Fig. 8*A*), were abundant in all hauls seaward of the 100-meter line, particularly in the Casco section and along the Nova Scotian side of the Bay of Fundy. The fact that the numbers of both late nauplii (17,938 per minute) and copepodites (32,404 per minute) at the entrance to the Bay (Station 8*A*) exceeded those found anywhere in the inner Gulf may indicate that immigrants from the western area are supplemented in June by contributions from another important production area, probably in the vicinity of the outer banks.[8]

Once the second brood had become generally dispersed offshore very little change was noted thereafter in the relative regional abundance of comparable stages during the remainder of the summer. In mid-August copepodites of the third and largest brood (Fig. 9*B*) were distributed in

[8] Since immigrant larvæ of other species, abundant at the time, showed no evidence of unusual concentration at Station 8A (Fish, 1936*a* and *b*), this condition in the case of *Oithona* does not appear to have been due to local current action.

much the same manner as similar stages of the preceding brood in June (Fig. 8*A*), being abundant at all offshore stations. Late nauplii of the same brood (Fig. 9*A*) were somewhat more restricted, with concentrations west of Penobscot Bay and in the drift entering the Bay of Fundy.

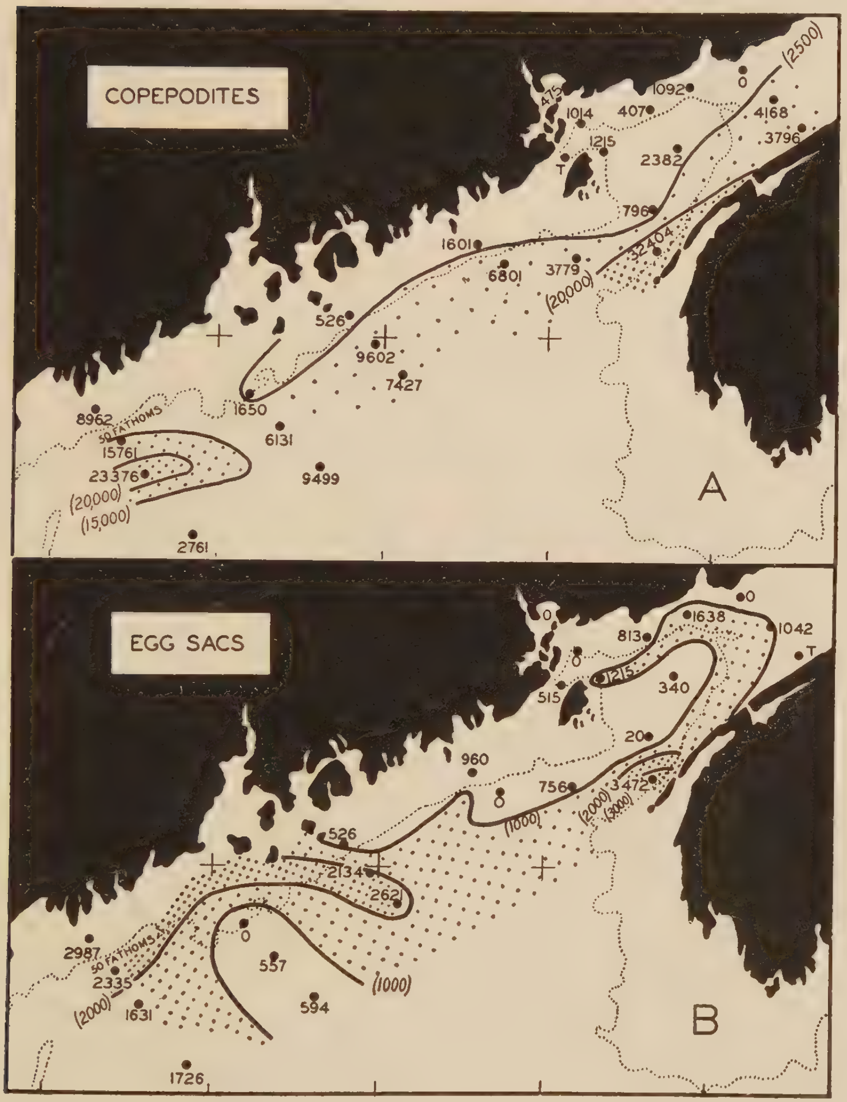

FIG. 8. Occurrence of copepodites of the second brood of the western stock and egg sacs of the second brood of the eastern stock in June, 1932. Number per minute of towing.

The coastal area east of Penobscot Bay and including the Bay of Fundy would appear to be relatively unproductive. The Bay apparently derives at times an abundant supply of nauplius stages from the eastern basin (Fig. *9C*), but the eastern coastal region of the Gulf was found to be populated for the most part with a relatively small immigrant stock in more advanced stages (copepodites and adults). The large numbers of nauplii entering the Bay of Fundy along the Nova Scotian side must decline rapidly in the cold turbulent waters for there is little evidence that they survive the circuit of the Bay and are dispersed westward in the drift along the coast of Maine. The most probable source of the late stages found in the latter zone, east of Mt. Desert, is that portion of the drift from the outer Gulf and eastern basin passing westward across the entrance to the Bay.

By mid-September the *Oithona* population had greatly declined in the Bay of Fundy. Observations were not made in the Gulf after August, but in view of the absence of an appreciable influx in the entering drift it is probable that the Bay reflected conditions throughout the region.

Eastern Stock.—The first brood of the stock maturing in the eastern part of the inner Gulf and Bay of Fundy was just appearing near its southern and western margins in late April. Eggs were found in the eastern basin, over German Bank, and in a limited portion of the western basin, but where vernal warming was delayed in the more turbulent eastern coastal zone of the Gulf and the Bay there was as yet no evidence of propagation. Egg sacs west of Mt. Desert were all found in the drift from the eastward and were probably derived from a parent stock transported from the eastern basin (Fig. *6B*). No eggs were found in the coastal zone anywhere in the Gulf.

By late May this first brood consisted largely of late copepodite stages which had become generally dispersed both in inshore and offshore waters, being most numerous well inshore in the western area (Fig. *7B*). Some in the warmer western coastal zone had apparently passed through the final moult, for as indicated by the scarcity of eggs (Fig. *7A*) at the innermost station off Casco Bay (Station *25A*) adults there (Fig. *2A*) were sexually immature and probably represented for the most part members of the eastern stock.[4]

Further evidence that only those eggs transported beyond the eastern coastal region before hatching survive, is seen in the composition of the eastern stock at this time. Since propagation had not begun in the inner Gulf east of Mt. Desert by the end of April, the product of this

[4] The western stock offshore had already spawned at this time (Fig. *7A*).

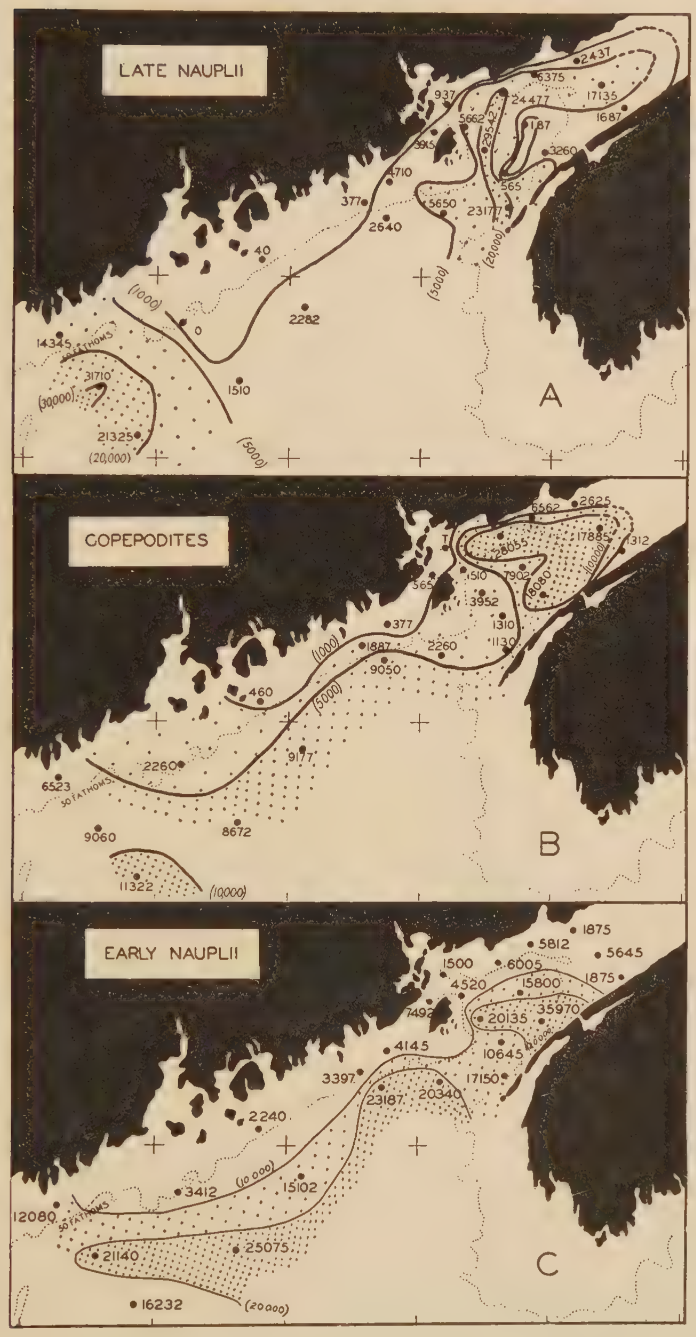

FIG. 9. Occurrence of late nauplii and copepodites of the third brood of the western stock, and early nauplii of the third brood of the eastern stock in August, 1932. Number per cubic meter.

late seasonal spawning a month later should have been represented by late nauplius stages, but very few were found. The young occurring in this region were copepodites assumed to be immigrants from more favorable production areas.

The distribution of eggs of the second eastern brood in late June (Fig. 8*B*) corresponded closely to that of the parent stock in the previous month (Fig. 7*A*). They were most numerous at the innermost stations in the Gulf and along the course of the drift into the Bay.

In mid-summer *Oithona* appeared to withdraw from the coast and the third eastern brood, in egg and nauplius stages, was found in August centered in the eastern basin and extending eastward into the Bay of Fundy and westward along the outer stations to the western area (Fig. 9*C*).[5]

TABLE III

Mean numbers of Oithona similis in the Gulf of Maine in 1931 and 1932. Number per cubic meter.

Stage	Gulf of Maine			
	Western Area		Central Area	
	1931 (Aug. 21–25)	1932 (Aug. 11–14)	1931 (Aug. 26)	1932 (Aug. 8–15)
Egg sac	1,947	1,855	1,409	1,224
Early nauplius	11,765	15,363	8,044	10,981
Late nauplius	12,018	15,529	21,133	11,175
Copepodite	7,908	7,217	9,220	5,144
Adult	3,537	2,557	3,575	3,090

As in the case of the western stock, there must have been a great decline in the third eastern brood in late summer. In the Bay of Fundy by mid-September the survivors in late nauplius and copepodite stages were found entering along the Nova Scotian side in numbers not exceeding 3,000 per cubic meter.[6]

Annual Variation.—In the Gulf the mean numbers of larvæ and adults in August of the two years were of a somewhat similar order. In 1931 (August 21–26) there were 35,044 larvæ and 3,556 adults per cubic meter, and in 1932 (August 8–15), 32,705 larvæ and 2,824 adults. However, the mean for the Bay of Fundy at the beginning of September in 1931 was more comparable with that of mid-September than of mid-August of the following year. In 1932 larvæ declined from 37,716 on August 17–21 to 3,262 per cubic meter on September 15–16, and adults from 3,120 to 332. The decrease had apparently already taken place in the Bay by September 1–5 in 1931, when the mean number of larvæ, 4,826, was almost as low as in the previous year in mid-September and the number of adults, 94, even lower.

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[5] Within the region of observations in the Gulf in 1932, copepodites of the eastern stock in May (Fig. 7*B*) and eggs in June (Fig. 8*B*) were most abundant in the coastal zone westward from Mt. Desert.

[6] In August in this area early nauplii were found up to 35,970 per cubic meter.

Considered by areas, in the Gulf the total numbers and relative percentages in comparable stages exhibit no very striking differences (Table III). A similar condition in the case of *Calanus* (Fish, 1936*a*, p. 130) and *Pseudocalanus* (Fish, 1936*b*, p. 202) has been interpreted to mean that in 1931 the season was delayed about two weeks. Adults were slightly more numerous in both the central and western areas in 1931. The mean number of larvæ was higher in the western area in 1932, and in the central area in 1931.

TABLE IV

Mean numbers of larval stages of dominant species of copepods in the total region in 1932. April–June: number per minute. August–September: number per cubic meter.

1932	Calanus finmarchicus	Pseudocalanus minutus	Oithona similis
April	2,007	7,126	1,112
May	7,024	11,484	5,918
June	2,156	21,303	8,919
August	977	5,639	34,852
September	41	3,506	3,262
April–Sept	(Mean) 2,441	9,812	10,813

RELATIVE NUMERICAL STRENGTH OF O. SIMILIS IN THE ZOÖPLANKTON POPULATION

Owing to its small size, *Oithona similis* is not taken in representative numbers in plankton nets of the type usually used in American waters, and for this reason former available records do not indicate accurately its relative abundance in the boreal population of the western Atlantic. Its presence in large numbers in collections from the Newfoundland region whenever there was a considerable amount of ctenophore debris (Pinhey, 1926) would indicate that it is abundant in those waters in late summer, but was captured only when the meshes of the net became partially clogged. As far south as Chesapeake Bay *O. similis* has been found by Wilson (1932) to form an important addition to the winter plankton. In the eastern Atlantic Gran (1902) reported that this species also plays an important rôle off Norway, and Ruud (1929) in the same region found it comprising up to 60 per cent of the copepod stock in July, 1925.

In the present investigations *Oithona similis* rarely appeared in the coarse meter net samples, but an estimate of its importance in the region during the spring and summer months can be obtained by comparing the relative abundance of larvæ with those of other dominant species. In making such a comparison it must be borne in mind that the relative numbers of young do not necessarily indicate that adults occur in the same proportion. The mortality of developing young appears to be very much greater in some species than in others and, like *Pseudocalanus* (Fish, 1936*b*), a very small percentage of *Oithona* larvæ apparently reach maturity. Again, because of its small size *Oithona* in the adult form must rank far below *Calanus* and *Pseudocalanus* in importance. However, it is not the adult stock of *Oithona* but the tremendous numbers of larvæ produced by this prolific species which appears to be of greatest significance in the economy of the region. Particularly in August it must form a most important source of food for those species feeding on larval copepods. In Table IV it will be seen that, based on the mean numbers of young between April and September (1932), *Oithona* ranks with *Pseudocalanus* and far exceeds *Calanus*.

Of added importance in the economy of the region is the fact that the seasonal maxima of the three species occur at successively later periods during the summer. Whereas *Calanus* reaches its peak in May (first brood), *Pseudocalanus* is most abundant in June (second brood), and *Oithona* (third brood) in August.[7] In the latter month the mean of *Oithona* larvæ for the entire region amounted to 34,852 per cubic meter.

SUMMARY

1. *Oithona similis,* although almost world-wide in distribution, is centered largely north of Cape Cod on the western Atlantic coast, and south from this point is gradually replaced by *O. brevicornis*.

2. The adult stock in the Gulf of Maine appears to approach the coast from offshore with rising temperatures in the spring.

3. Propagation begins in the Gulf in March and continues in a succession of generations until September.

4. Two breeding stocks are distinguishable, due to an average difference of about one month in the time of vernal propagation in the

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[7] To this seasonal progression may be added a September maximum of *Centropages typicus* larvæ throughout the Gulf and Bay of Fundy.

eastern and western parts of the region. This difference is reflected in subsequent generations after dispersal.

5. There appear to be four broods of the western stock, in March, May, July, and September, and three in the eastern, in April, June, and August.

6. A developmental period of two months during the early season and about six weeks in summer is indicated.

7. *Oithona* is at times far more prolific than either *Calanus* or *Pseudocalanus,* but mortality is relatively much higher, depletion being greatest in nauplius stages.

8. The western stock remained for the most part concentrated offshore, but the eastern, particularly in advanced stages, was more generally distributed, sometimes being more abundant inside than outside of the 100-meter contour.

9. There is some evidence that in June the local stock in the inner Gulf is supplemented by important contributions from another production area, probably in the vicinity of the outer banks.

10. There is no indication of successful propagation in the turbulent coastal region of the Gulf east of Mt. Desert or in the Bay of Fundy.

11. The larvæ of *Oithona* afford the most abundant source of food in the region in mid-summer for those animals feeding on larval planktonic organisms. Of added importance in the natural economy of the region is the fact that the seasonal maxima of the three numerically dominant species occur at successively later periods during the summer, *Calanus* in May, *Pseudocalanus* in June, and *Oithona* in August.

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THE OCCURRENCE AND SIGNIFICANCE OF NITRITE IN THE SEA

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In studying the nitrogen cycle in the sea a consideration of the nitrite concentration in the water is especially useful, because of its intermediate position between ammonia on the one hand and nitrate on the other. Although it is not a stable end-product, its very instability makes it a possible indicator of the state of equilibrium between the oxidation and reduction processes making up the cycle. Its order of magnitude in the water is much smaller than that of nitrate, or even ammonia, but the methods for its analysis are correspondingly more accurate, so that its normal variations may be followed as closely as those of the other nitrogen compounds.

In view of the ease with which nitrite determinations may be made, it is surprising that there are not more data on its occurrence in sea water. Raben (1914, 1918) and Brandt (1927) were among the first to report such figures, but their data were only scattered and fragmentary. Orr (1926) reported some analyses of samples from the vicinity of the Clyde Sea, made observations on diatom cultures, and discussed the factors concerned in the appearance and disappearance of nitrite. Harvey (1926) failed to find significant amounts of nitrite in the English Channel or in deeper waters of the Atlantic further south, but noticed their occasional appearance in stored samples. Atkins (1930), however, was able to make a fairly comprehensive study of the seasonal changes in nitrite in the English Channel, finding high concentrations at certain levels and at certain times. Orton (1924), investigating various influences upon the growth of oysters, found moderately high concentrations in samples from Plymouth Sound, Thames Estuary and Helford River. He also followed nitrite changes in the water of storage tanks.

In a few cases, figures for nitrite have been reported incidentally, or in connection with other chemical studies of sea water, as by Braarud and Klem (1931), Robinson and Wirth (1934), Rakestraw (1932, 1933), Matsudaira and Yasui (1932, 1933), and in connection with the Antarctic cruises of the "Discovery" (1932). Three good seasonal studies have appeared more recently, by Soot-Ryen (1932), Verjbinskaya (1932), and Cooper (1933). The last of these is most comprehensive, containing very complete data for the relationship between various chemical factors in the water. Unfortunately, its limitation to one or two shallow stations in the English Channel raises a question as to the validity of its conclusions when applied to other, more general conditions.

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[1] Contribution No. 110.

The present paper includes results collected over a period of five years at the Woods Hole Oceanographic Institution in the effort to explain the production and utilization of nitrite and its place in the nitrogen cycle of the sea and the general process of marine metabolism. The data include analyses from:

1. A small group of inshore stations in shallow bays.
2. Stations on the continental shelf to the south of Cape Cod, including two serial sections to the edge of the shelf.
3. A number of stations in the Gulf of Maine, so grouped as to indicate seasonal variations for more than a year, at seven different locations.
4. A group of deep sea stations to the south of Cape Cod, from the edge of the continental shelf to Bermuda, at different times of the year.
5. Stations to the south of Bermuda, across the edge of the Sargasso Sea to the Bahamas, and fifteen stations in the Caribbean.
6. A large number of scattered surface samples, at various places and times.
7. Bottom muds and waters contained in them.
8. Samples stored under a variety of conditions.

Methods

The Griess-Ilosvay method, used in this work as in that of practically all previous investigators, has been repeatedly described, with minor variations. It depends upon the color developed in the sample by means of sulphanilic acid and alpha-naphthylamine (or its dimethyl or diethyl derivative). Buch (1923) established its suitability for sea water by a careful spectrophotometric study. It is simple, reliable and not easily susceptible to temperature changes and other fortuitous factors. There is no salt effect upon the color development, so that standards may be made up in distilled water. It was easily established that the color developed was constant between 2 and 48 hours, an adequate range for routine purposes.

Two milliliters of sulphanilic acid solution (8 grams in 1 liter of

30 per cent acetic acid) are added to 100 ml. of the sample, followed by 2 ml. of a solution of alpha-naphthylamine, or diethyl-alpha-naphthylamine (8 grams in 1 liter of 30 per cent acetic acid, with 10 ml. of conc. HCl added). After two hours or more the samples are compared with appropriate standards. This was done in a colorimeter of the Hehner tube type, which has long been used in this laboratory for phosphate, nitrite and other determinations.

We have seldom had trouble in obtaining nitrite-free distilled water (as Cooper seems to have had), and have very frequently found sea water samples free of nitrite to the limit of sensitivity of the method, which is well under .005 microgram atom per liter. Stock standards have been made either from sodium nitrite or from silver nitrite, precipitated by NaCl. In either case, such solutions may be preserved for many weeks and their concentrations checked by titration with $KMnO_4$, or iodimetrically. Dilute standards for use are prepared from these and kept for not longer than one day.

TABLE I

Accuracy of the analytical method for nitrite.

Depth in meters	Triplicate analyses			
	A	B	C	
30	4.3 .307	4.3 .307	4.4 .315	mg./cu. m. μg. at./liter
40	1.9 .135	1.9 .135	1.9 .135	mg./cu. m. μg. at./liter
50	1.6 .115	1.6 .115	1.65 .118	mg./cu. m. μg. at./liter

Throughout this work results will be expressed in microgram atoms per liter, according to the recent recommendations of the International Council. These may be translated into the older units of milligrams of nitrite-nitrogen per cubic meter by multiplying by 14.

In order to indicate the accuracy and reproducibility of results by this method there are given in Table I the results of triplicate analyses (A, B, C) on three different water samples, expressed in both the old and new systems of units. Later results are given to the nearest .005 microgram atom.

VARIABILITY OF NITRITE

As far as our experience goes, the nitrite concentration in sea water varies normally from 0 to .35 microgram atom per liter. Occasional values up to double this amount have been encountered, and the highest found (in Cape Cod Bay) was .91. No values like those reported by Atkins (2.78, or 38.9 mgm./m.^{3}), or by Matsudaira and Yasui, in the Yellow Sea, have ever been found in normal waters on this side of the Atlantic.

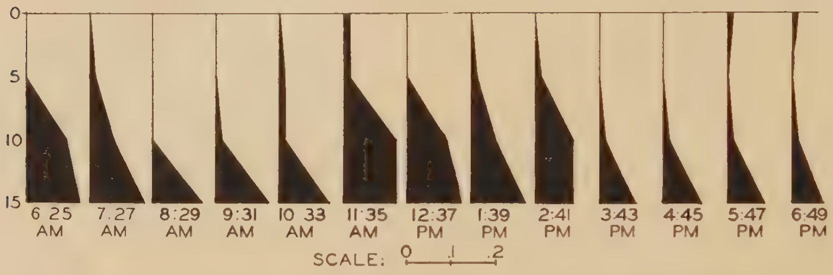

FIG. 1. Variation of nitrite during a tidal cycle. Station K-2, Buzzards Bay. Ordinates, depths in meters.

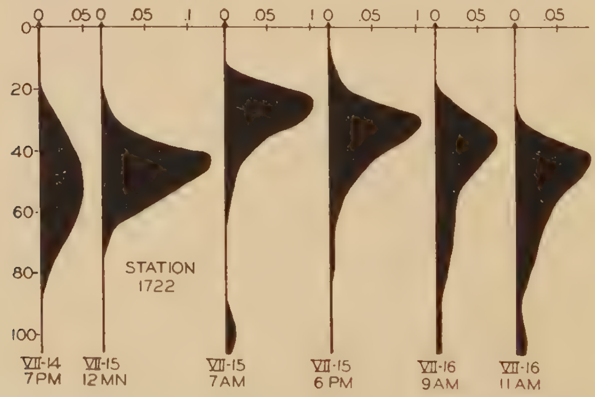

FIG. 2. Variation of nitrite during a tidal cycle. Station 1722, Gulf of Maine. Ordinates, depths in meters.

Nitrite is one of the most variable factors in the sea. Analyses from two stations close together, or from the same station at different times not far apart, sometimes yield quite different results. In fact, the horizontal distribution of nitrite is highly dependent upon local conditions. This would be better appreciated if previous data had not been so scattered and incomplete. Cooper seems to have been the only one sufficiently well aware of the fact.

In view of this, it is rather surprising that any general trends can be seen and conclusions drawn. Absolute values for nitrite concentration, especially isolated ones, are of little use; only by a comparison of relative amounts, with fairly complete data, can one obtain a clear picture of conditions.

To show how general trends do appear, however, the nitrite concentration was followed at two stations (K–2 and 1722) throughout a complete tidal cycle. The results are shown in Figs. 1 and 2. Here, as in all the subsequent figures, the vertical distribution of nitrite is represented by a solid black area.

The vertical variation in nitrite concentration is one of the most striking and interesting facts concerning it. As will later be shown, both the production and utilization of nitrite are processes taking place in particular, but different, layers. This often gives rise to large vertical differences, and usually, in the summer, a maximum zone, of variable depth, sharpness and intensity. Good examples of this are found in Atkins' results from the English Channel. Strangely, Cooper's data from the same location, a few years later, fail to show the phenomenon —probably, as he suggests, due to different hydrographic conditions that year.

TABLE II

Stations in shallow bays. Nitrite concentrations in microgram atoms per liter.

Station:	K-1	K-2	K-3	L-1		L-2		R-3	R-4	S-1	S-2
Depth in meters	8-30 1931	8-30 1931	8-30 1931	7-18 1931	8-28 1931	7-18 1931	8-28 1931	8-26 1932	8-26 1932	7-14 1932	7-14 1932
0	0	0	0	0	0	0	.07	0	0	0	0
5	0					0	.01	0	.41		
10	.01	0	0	0	.01	0	.10	.085		.61	.86
15		.01									
20			.01	0	.01	0	.085		.43		.20
40										.91	

The nitrite concentration in bottom muds is most highly variable and will receive special attention later.

All this variability in nitrite concentration is only to be expected from the precarious position which it occupies in relation to other substances in the water. Conceivably, it may be produced by oxidation of ammonia or reduction of nitrate, by means of bacteria, catalytically or photochemically. It is not impossible that the phytoplankton may play a part in the oxidation or reduction. In any event, nitrite is one step in the process of decay and "mineralization" of organic matter, either formed or particulate, or dissolved in the water.

On the other hand, nitrite may be destroyed by: (1) oxidation to nitrate or reduction to ammonia—atmospherically, photochemically, or by bacteria; or, (2), consumption by phytoplankton. We cannot be altogether certain whether or not free nitrogen enters into the process in any way. However, at any moment, the concentration of nitrite is an expression of the equilibrium between production and destruction.

TABLE III

Stations on the continental shelf, near Cape Cod. Nitrite concentrations in microgram atoms per liter.

Station:	1270	1295	1271	1296	1272	1297	1273	1298	1260	1299
Depth in meters	6-29 1932	7-20 1932	6-29 1932	7-20 1932	6-29 1932	7-20 1932	6-29 1932	7-21 1932	6-28 1932	7-21 1932
0	0	—	.06	—	.01	.05	.07	—	—	—
10	0	0	0	0	0	0	.01	0	0	.01
20	.01	0	0	0	0	.01	.01	0	0	.01
30		.01		.115		.235		.01		0
40		.085	.07		.14		0			
50								.41		
60						.09			.23	.19
75					0		.26	.36		
100										
125									0	.01
150										
175										.01

Station:	1261	1283	1282	1281	1280	1725	1739	1684	2143	2156
Depth in meters	6-28 1932	7-1 1932	7-1 1932	7-1 1932	7-1 1932	7-25 1933	7-31 1933	7-27 1933	5-8 1934	5-11 1934
0	0	0	0	0	0	0	0	0	.04	0
10		0	0	0	0	0	0	0	.05	0
20	0	0	0		0	0	.02	0	.06	0
30		.17	0	0			.44	.01	.07	0
40		.065				.44	.39	.01		
50			.06	.33	0		.36	.12	.08	.085
60						.20	.24	.03		
75							.36	0	.12	.11
100	.01			.20	.07	.02		0	.18	.27
125								.01	.26	.26
150						.03		.05	.17	.07
175					.05				.05	.08
200	0									.01

The distribution of nitrite may therefore be related to a large number of factors: the distribution of bacteria, phytoplankton and zoöplankton; temperature; light intensity; oxygen tension in the water; density and circulation of the water; and perhaps other seasonal influences.

TABLE IV

Serial sections on the continental shelf. Nitrite concentrations in microgram atoms per liter.

Line "A"
July–August, 1931

Depth in meters	Miles off:									
	1	2	5	7	10	13	39	61	82	90
0	0	0	0	0	0	0	0	0	0	0
10	.07			0	0	0	0	.09	0	
25		.13	.06	.04		.10			0	0
35					.03	.115				
50									0	0
65							.40			
100								.135		0
565									.035	
885										0

Line "D"
August 5–6, 1931

Depth in meters	Miles off:								
	1	2	5	10	20	30	40	50	66
0	0	0	0	0	0	0	0	0	0
10			0						
20	.05	.01		0	.01	0	0	0	0
40			.09	.215					
60					.66				0
75						.05	.15	.165	
100									0
200									.035

DESCRIPTION OF DATA

The results from shallow, inshore stations, shown in Table II, were mostly obtained in the early stages of the work and are useful in demonstrating that the occurrence of nitrite is not closely associated with such influences as land drainage. Although concentrations are usually low, there are exceptions, as at Stations S–1 and S–2, where the highest concentrations of all were found. Great differences in local conditions evidently exist.

The stations on the continental shelf, shown in Tables III and IV, and in Fig. 3, present a fairly regular picture. Since these were all sampled during the summer months, nitrite was seldom found at the surface in more than small traces, while significant amounts were encountered below 30 meters, or near the bottom, if shallower than that. Surface conditions off New York Harbor were somewhat exceptional. Lines *A* and *D*, to the edge of the shelf, bring out the fact that the rate of nitrification on the bottom, as indicated by nitrite concentration there, is apparently greatest at depths of 50 to 75 meters. The numbering of stations on these lines (*A*–5, *A*–39, *D*–20, etc.) indicates the number of miles off-shore, in each case. An unfortunate spacing of the sampling levels at the deeper stations on these lines, as well as elsewhere on the shelf, failed to reveal the zone of maximum nitrite generally found at such stations between 30 and 50 meters, and which probably existed here also. At the deepest stations, along the edge of the shelf (1725, 1684, 2143 and 2156), this maximum zone is clearly seen. Its depth varies considerably, showing the influence of the adjacent oceanic water, in which the maximum zone is invariably deeper than at stations on the shelf.

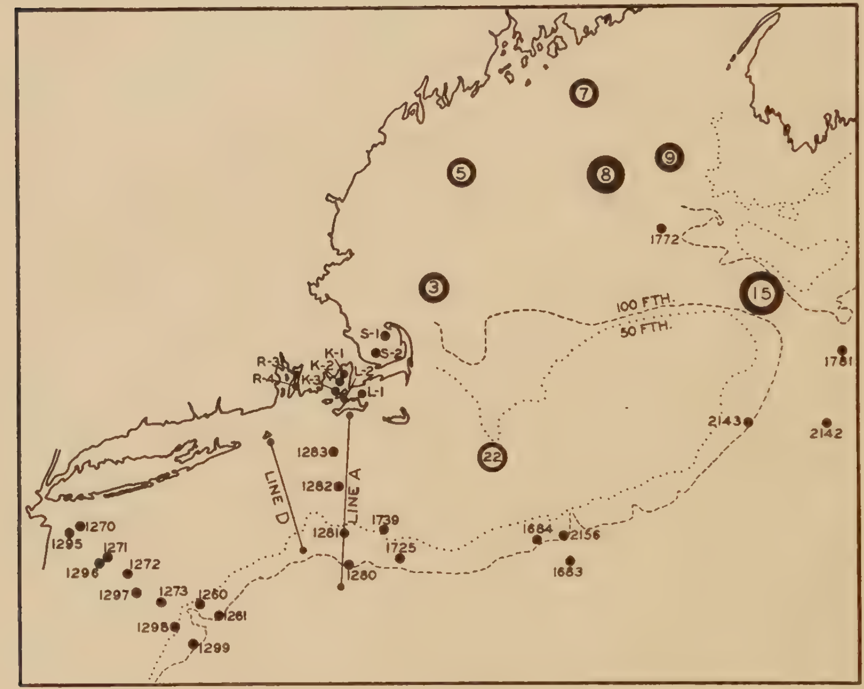

Fig. 3. Location of stations in the Gulf of Maine and vicinity.

TABLE V

Deep sea stations, Cape Cod to Bermuda. Nitrite concentrations in microgram atoms per liter.

	Group 1			Group 2				Group 3					Group 4		Miscellaneous							
Station:	1731	2313	2455	1732	2315	2456	2457	1462	1734	2316	2458	2460	1465	2317	1463	1640	1683	1730	1781	2142	2450	2451
Depth in meters	7-26 1933	1-21 1935	7-22 1935	7-27 1933	1-21 1935	7-22 1935	7-23 1935	2-7 1933	7-28 1933	1-23 1935	7-23 1935	7-24 1935	2-10 1933	1-23 1935	2-7 1933	5-17 1933	7-27 1933	7-27 1933	9-10 1933	5-7 1934	7-21 1935	7-21 1935
0	0	.02	0	0	.08	0	.01	—	0	.065	0	0	.16	.065	—	.10	0	0	0	0	0	0
10	0		0					.14					.01		.035		0	0	0	0		
20	0	.06	0	0	.15	0	0	.14	0	.065	0	0	0	.06	.01	0	0	0	0	.02	0	0
30	0			0									0		.01	0	0	0	0			
40	0							.15					.03				0	0	0	.12		
50	0	.30	.33	0	0	.215	.30	.135	0	.06	0	0	0	.03	.01	0	.08	0	.18		0	0
60	0			0				.15	0								.06	.03	.165	.38		
75	.20	.06		0	.16				.01	.05	0	0		0	.03		.01	.02	.05	.60		
100	.065	.04	0	0	.32	.14	.06	.21	.05	.06	0	0		0	.03	.06	.01	.02	.02	.51	0	0
150	.01	0		.05	.14			.185	.02	.065	0	0	0	.065	.035	.07	.02	.01	.02	.29	0	0
200	.01	0	0	0	.08	0	0	.185		.06	0	0	.03	.035	.01	.04	.03	.01	.02		0	0
250		0			.08				0	.065		0					.03		0	.01	0	0
300		0	0	.065	0	0	0	.01	0	.065	0	0	0	.06	0	.04	.02		0	0	0	0
400	.01		0	.01	0	0	0	.165	0	0	0	0	0	0	0	.01	.02	.01	.01	.01	0	.01
500			0			0	0	.07			0	0	.02	0	0	0	0		.01	0	0	0
600	0		0	.01	0			.01	.02	0	0	0	.03	0	0	0	0	.01	0	.02	0	0
800	0			0	0			.01	0	0	0	0	0		0	0	0	.06	0	0	0	0
1000	0			0	0			0		0	0	0	0		0	0	0	.01	.01	0	0	0
1100															0		0					
1200	0				0			.01			0	0	0		.01		0	0	.01		0	0
1400	0							0					0		0		0	0	.02			
1600	0							0					0		0			0	.02		0	0
1800													0						.01	0		
2000								0					0		0			0	.03	.02	0	0
2500													0		0						.035	.01
3000													0		.035							
3500															.04							
4000															0		0					

TABLE VI

Seasonal variation of nitrite in the Gulf of Maine. Nitrite concentrations in microgram atoms per liter.

Location 3

Station:	1284	XX	1699	1748	1857	1864	1909	2022	2074	2168	2220	2274
Depth in meters	7-12 1932	5-6 1933	7-3 1933	9-4 1933	10-19 1933	12-2 1933	1-9 1934	3-22 1934	4-18 1934	5-22 1934	6-26 1934	9-19 1934
0	0	0	0	0	.215	.09	.08	.085	.10	.01	.035	0
10	0	0	0	0		.08	.02	.085	.10	0		0
20	0	.06	0	0		.08			.115	0	.02	
30	0	.17	.01	0	.28	.08	.03	.11	.135	0	0	.11
40	.165		.14	.04						.22	.18	
50	.32	.20	.11		.21	.07	0	.085	.135		.135	0
60	.32		.07	.02		.065				.39	.09	0
80			.01	0	0	0	0	.09	.06	.14	.04	0
100	.02	.02	0	.03	.01	0	0	.085	.02	.115	.02	0
125			0	0				.065	0	.10	.02	0
150	0		.01	0	.01	0	.01	.04	0	.01	.03	0
175								.03	0	0	.01	0
200	.035		0	0	0	0	0		0	0	.02	0
225		0						.03	0	0		
250			0	0	0		0					0

Location 5

Station:	1287	1705	1761	1871	1911	2031	2083	2176	2224	2282
Depth in meters	7-10 1932	7-7 1933	9-6 1933	12-3 1933	1-9 1934	3-23 1934	4-19 1934	5-24 1934	6-28 1934	9-20 1934
0	.035	0	0	.035	0	.09	.11	.08	0	0
10		0	0	.035	0	.085	.115	0	0	0
20	0	0	.08	.02	0		.12	.18	0	
30	.10	.07	0	.02	0	.085	.115	.21	.28	.035
40	.25	.085	0	.02	0			.21	.235	
50	.09	.09	0	.02	0	.08	.12	.215	.215	0
60	.03	.04	0	.03	0			.185	.15	
80	.01	.01	0	.02	0	.05	.05	.115	.15	0
100	.01	.01	0	.01	0	.035	.035	.085	0	0
125	.01	.01	0	.01	0	.02	.03	.10	0	.01
150	.03	.01	0	.03	0	.03	.01	.05	0	0
175		.01	0		0	.035	0	0	0	0
200					0				0	

Table V contains the deep stations from Cape Cod to Bermuda. A number of these are located in roughly corresponding positions and are arranged in four groups accordingly. Of these, No. 3 is most complete, with four stations at different times of the year. These have been plotted in Fig. 8 to show the seasonal variations. At all these stations, the maximum zone is found between 50 and 100 meters, with only traces

TABLE VII

Seasonal variation in the Gulf of Maine (continued). Nitrite concentrations in microgram atoms per liter.

Location 7

Station:	1712	1765	1888	1916	2037	2089	2182	2286
Depth in meters	7-8 1933	9-7 1933	12-7 1933	1-10 1934	3-24 1934	4-20 1934	5-25 1934	9-21 1934
0	0	0	.03	.02	.065	.09	.12	.19
10	0	.01	.02	.01	.07	.10	.12	.35
20	.165	.16	.03	.01			.13	
30	.22	.215	.05	.01	.065	.10	.11	.33
40	.21	.16	.035				.11	
50	.18	.04	.05	0	.06	.12	.06	.31
60	.17	.035	.035				.06	
80	.17	.035	.03	0	.06	.13	.09	.30
100	.065	.035	.02	0	.065	.13	.10	.06
125	.02	0		.02	.06	.07	.085	0
150	.03	.01	.02	.02	.04		.08	0
175	.04	.02					.05	0
200			0					0

Location 8

Station:	1716	1764	1853	1886	1914	2035	2087	2180	2227	2288
Depth in meters	7-9 1933	9-7 1933	10-19 1933	12-6 1933	1-10 1934	3-24 1934	4-20 1934	5-25 1934	6-29 1934	9-21 1934
0	0	0	.32	.085	.06	.065	.04	.065	0	0
10	0	0		.08	.06	.05	.05	.01	0	0
20	0	0	.28	.085			.11	.03	.24	
30	.115	.07		.07	.05	.06	.115	.11	.085	.10
40	.21	.01	.40	.08				.08	.07	
50	.215	0		.085	.03	.05	.115	.165	.05	.04
60	.12	.01	.15	.085				.17	.05	
80	.02	0	.16	.07	.01	.06	.08	.17	0	0
100	0	.02	.08	.085	.01	.01	.035	.15	0	0
125	0	.02				.01	.03	.135	0	.035
150	.04	.01	.01	0	0	0	0	.13	0	.01
175	.02	0			0	0	0	.09	0	0
200		0	.08	0		0	0	.05	0	.01
225					0	0	0	0		.04
250		0			0					0

of nitrite below this. Only during the winter months is nitrite found at the surface. The extremely sharp maximum zone at Station 1781 may be noted, at which nearly all the nitrite in the water column occurs in a twenty-meter layer, somewhat nearer the surface than at stations further to the south.

Stations in the Gulf of Maine, shown in Tables VI, VII and VIII are grouped into seven "locations." These include Location 22 on Georges Bank, which may be considered an adjunct to the Gulf of Maine. The separate stations in each of the locations are close enough

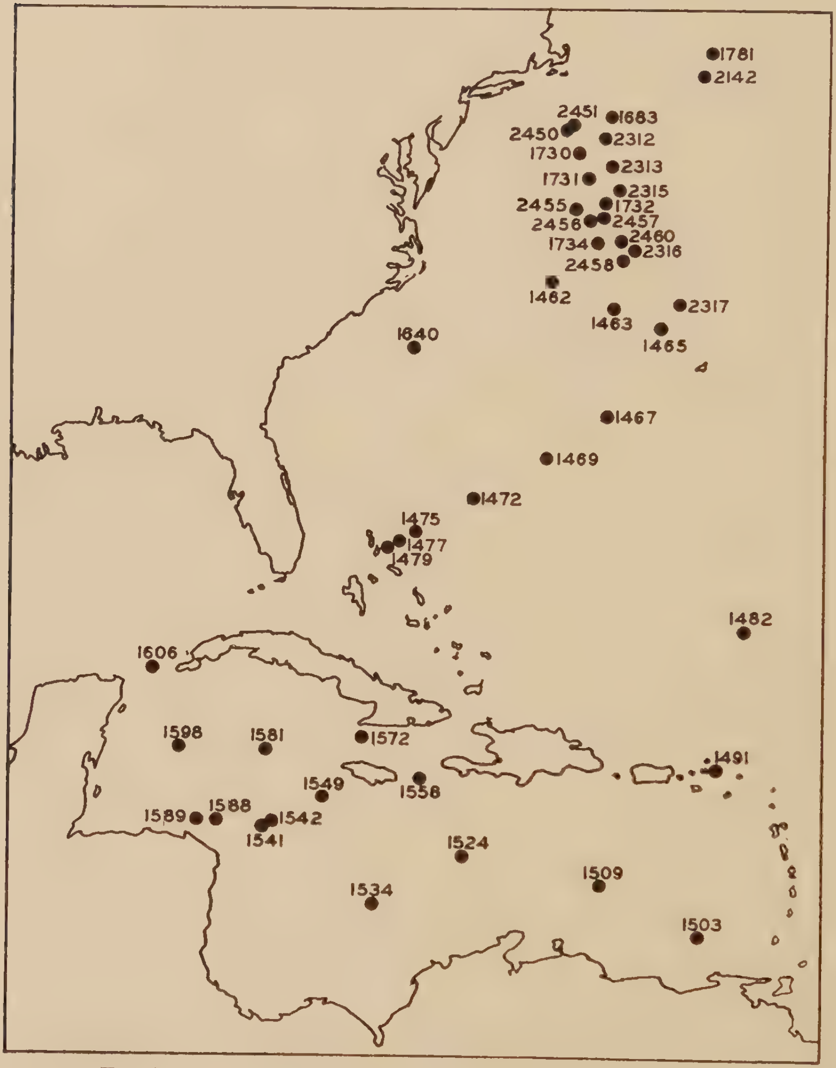

FIG. 4. Location of stations from Cape Cod to the Caribbean.

together to be comparable, and were visited on different cruises at various times of the year, covering a total period of thirteen months or more. The data from six of these locations have been plotted in Figs. 5, 6, and 7 to show the seasonal variations of both nitrite and nitrate. The data from Location 9 (not tabulated) are shown in Fig. 12, to indicate the relation between nitrite concentration, temperature and density.

These figures from the Gulf of Maine are but a small portion of the analyses made during a survey of that region, the results of which will appear at a later time.

Table VIII

Seasonal variation in the Gulf of Maine (continued). Nitrite concentration in microgram atoms per liter.

Location 15

Station:	1659	1781	1846	1899	1924	2052	2118	2137	2197	2296
Depth in meters	6-22 1933	9-10 1933	10-19 1933	12-7 1933	1-11 1934	3-26 1934	4-30 1934	5-6 1934	5-28 1934	9-23 1934
0	0	0	.19	.14	.11	.085	0	0	.01	0
10	0	0		.135			0	0	0	0
20	0	0	.14	.15	.065	.085	.07	0	0	
30	.01	0		.15			.11	0	0	0
40	.02	0	.19	.085	.06	.10			0	
50	.06	.18		.08			.115	.11	.065	.01
60	.09	.165	.11	.035	.06	.10			.115	.11
80	.05	.02	.01	0	.01	.10	.08	.16	.185	.265
100	.05	.02	.02	0	0	.07	.16		.085	.07
125	.01	.02				.01	.135	.04	.01	
150	.01	.02		0	0	0	.13	.05	.03	.035
175	.01	.01				0	.03	.03	.115	.02
200	.01	.02	.02	0	0	.07		.01	.115	.01
225						.06			0	
250	.01	0	.02	0	0	0		0		0

Location 22

Station:	1686	1742	1934	2069	2154	2214	2269
Depth in meters	7-27 1933	9-3 1933	1-13 1934	3-29 1934	5-10 1934	6-2 1934	9-18 1934
0	0	0	.03	—	.05	.05	.04
10	0	0		.035	.04	.06	.06
20	.03	.085	.035		.035	.04	
30	.035	.15		.03	.035	.05	.08
40	.04	.165	.03			.05	
50	.04	.18		.07	.03	.05	.15
60	.04	.185	.03	.035		.05	
80		.185				0	.21

The stations to the south of Bermuda, including those in the Caribbean (Table IX), present a rather different picture from that in the north. Generally, smaller amounts of nitrite are found, but frequently relatively large amounts at the surface. The maximum zone is near 100 meters, sometimes sharp, sometimes poorly defined.

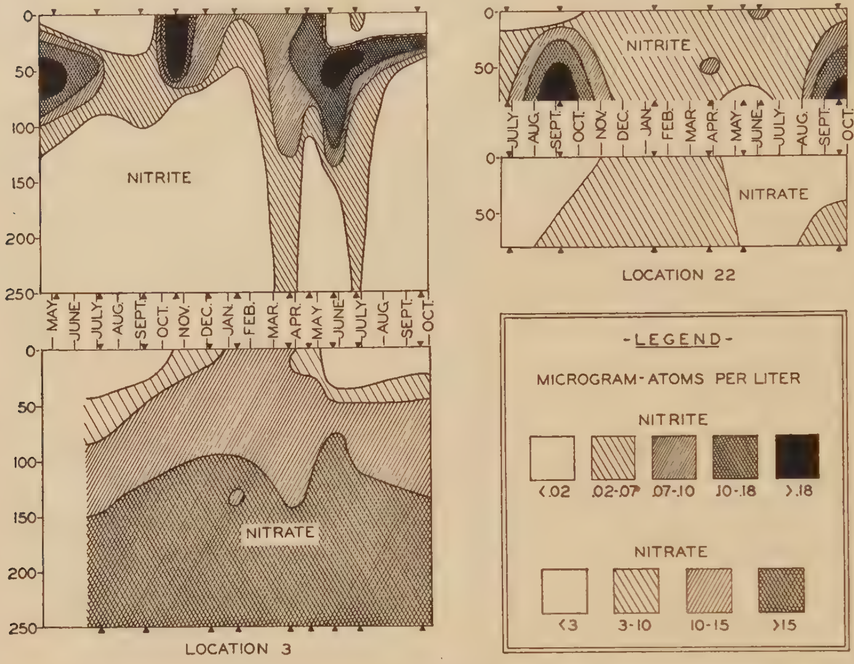

Fig. 5. Seasonal variation of nitrite and nitrate. Locations 3 and 22, Gulf of Maine. Ordinates, depths in meters.

Relation of Nitrite to Other Factors

Nitrate and Phosphate

Since nitrite participates in the metabolic cycle with the other "nutrient salts," it would seem important to compare its variations and behavior with that of the other nutrients, nitrate and phosphate.

Figures 9 and 10 show these relations at a number of stations in the Gulf of Maine at various times of the year. Certain conclusions are evident:

1. High nitrite concentrations in the upper water levels are associated with high concentrations of nitrate and phosphate. The converse is not always true, especially at certain times of the year. During the winter, when the surface is being replenished with nutrients by overturn of the water mass, nitrite is also in evidence, particularly as the season advances. In January, the production of nitrite is at a minimum, and since this corresponds to the time of greatest instability of the water mass it occasionally happens that little or no nitrite is found at any level,

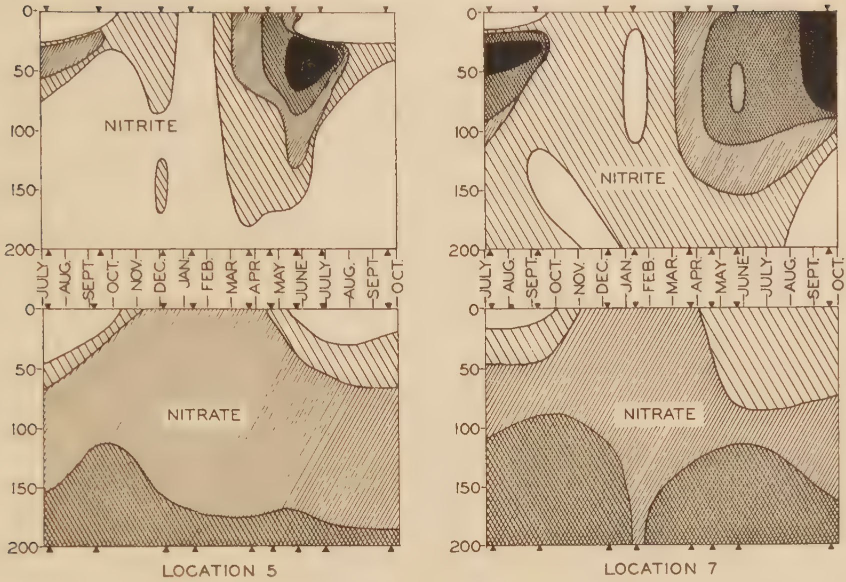

FIG. 6. Seasonal variation of nitrite and nitrate. Locations 5 and 7, Gulf of Maine. (See Fig. 5 for legend.) Ordinates, depths in meters.

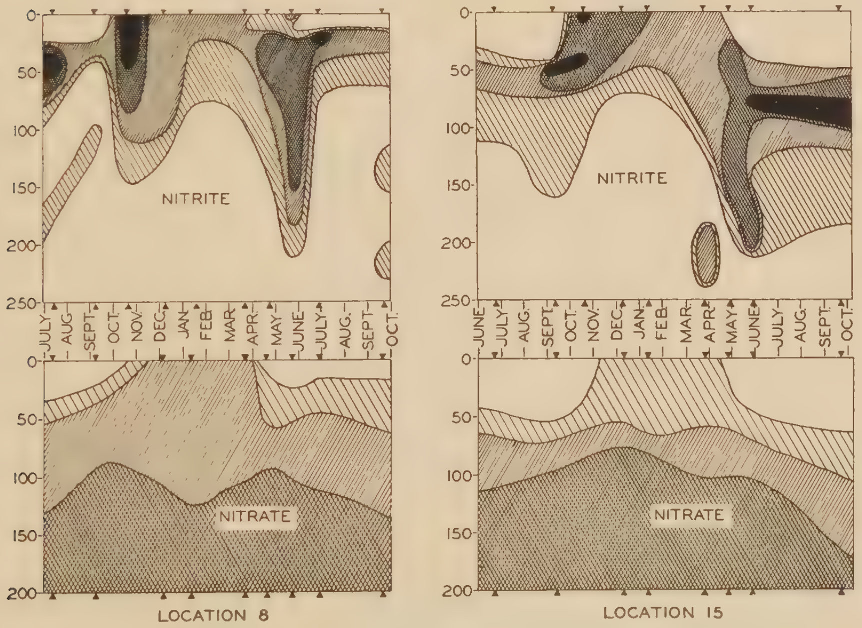

FIG. 7. Seasonal variation of nitrite and nitrate. Locations 8 and 15, Gulf of Maine. (See Fig. 5 for legend.) Ordinates, depths in meters.

even though there is abundant nitrate. This condition obtains at Stations 1908 and 1910.

2. High nitrate and phosphate in the *deeper* water is not associated with nitrite. The latter is seldom found in large amounts below 100 meters. It is evidently produced near the surface and works down through the unstable layer during the winter until stratification again sets in.

3. When diatom growth begins in the spring, with the utilization of nitrate and phosphate, nitrite also disappears in the surface water. At Station 2099 this process has apparently just begun, while at 2098 the season is further advanced, nitrate and phosphate are down almost to their summer values at the surface, and nitrite is absent. Figure 10 is compiled from a number of stations during the summer months to show the close correlation between the gradients of nitrite, nitrate and phosphate near the surface. The origin points for nitrite and nitrate coincide in these diagrams, but the phosphate curves are arbitrarily displaced to the left to facilitate comparison. The shape, slope and position of the curves indicate that the same conditions govern all three. As a consequence of this correlation, it is proposed that nitrite, which is normally produced near the surface, is utilized by the phytoplankton during the period of its growth, in the same manner as nitrate and phosphate, so that the upper levels become depleted. If the upper right-hand corner of the nitrite area shown in Fig. 9 for Station 1896 (or 1884) were cut off, and the curves for nitrate and phosphate deflected towards the origin, a condition would be represented exactly similar to those in Fig. 10. This is what would be expected during July or September. Abundant evidence of the utilization of nitrite by diatoms is

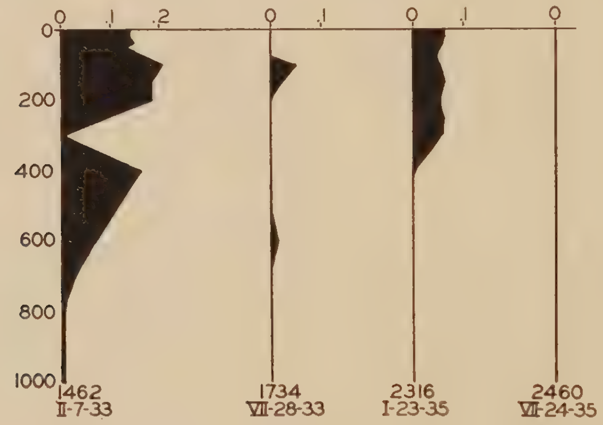

FIG. 8. Seasonal variation of nitrite at an oceanic station. (Group 3, Table V.) Ordinates, depths in meters.

TABLE IX

Stations south of Bermuda, including the Caribbean. Nitrite concentrations in microgram atoms per liter.

Station:	1467	1469	1472	1475	1477	1478	1482	1491	1503	1509	1524	1534	1541	1542	1549	1558	1572	1581	1588	1589	1598	1606
Depth in meters	2-14 1933	2-15 1933	2-17 1933	2-19 1933	2-19 1933	2-20 1933	3-3 1933	3-8 1933	3-15 1933	3-23 1933	3-29 1933	4-2 1933	4-4 1933	4-4 1933	4-5 1933	4-15 1933	4-25 1933	4-27 1933	4-29 1933	4-30 1933	5-1 1933	5-4 1933
0	0	.06	0	0	0	.01	.05	.07	.24	.35	.06	0	0	.04	.265	.04	.10	.165	0	.04	.01	.135
25	0	0	0	0	0	0	.01	.03	.14	.02	0	.02	0	.01		.02		0	0	0	0	.01
40	0	0	0	0	0	.02																
50					0		.05	.01	.18	.01	0	.01		0	.01	.01	.05	0	0	0	0	.01
100	0	.07	0	0	0	.035	0	.01	.05	0	0	.06		.32	.03	.02	.035	.185		.47	0	.11
150	0	.03	0	0	.11	.04	.03	.02	.035	.06	.035	.03		.02	.035	.04	.16	.035		0	.02	.035
200		.03			.01	.035	.035	.01	.01	.02	.02	.03		.02	.02	.02	.035	0		0	.01	.03
300	0	0	0	0	0	.01	.035	.09	.01	.01	0	.01			.02	.03	.03	0		0	0	.02
400	0	0	0	0	0	.01	.02	.02	.02	.01	0	.03			.01	.02	.02	0		0	0	.01
500		.01	0	0	0	.01	.02	.01	0	.01	0	.01			.02	.03	.01	0		0	.01	.01
600	.01	0	0	0	0		0	.04	.01	0	0	.02			.01	.02	.02	0		0	0	.01
700							.02	.04	.02											0		
800	0	0	0	0	.01		.01			0	0	.01			.01	.02	0				0	.01
900		0			.01		.01	.035		0												
1000	0	0	0	0	0		0	.01			0	.01			0	.02	.01					
1100							.03	.01														
1200	0	0	0	0	.01			.02			0											
1400	0	0	0	0	0		0	.02			0						.01					
1600	0	0	0	.01	.01		0	.02														
1800	0	0						.04														
2000	0	0	0	0	0		0				0						0					
2500			0	0	0		0				0											
3000	0	0		0	0		0				.01						.01					
3500											0											
4000	0	0									.01						.01					

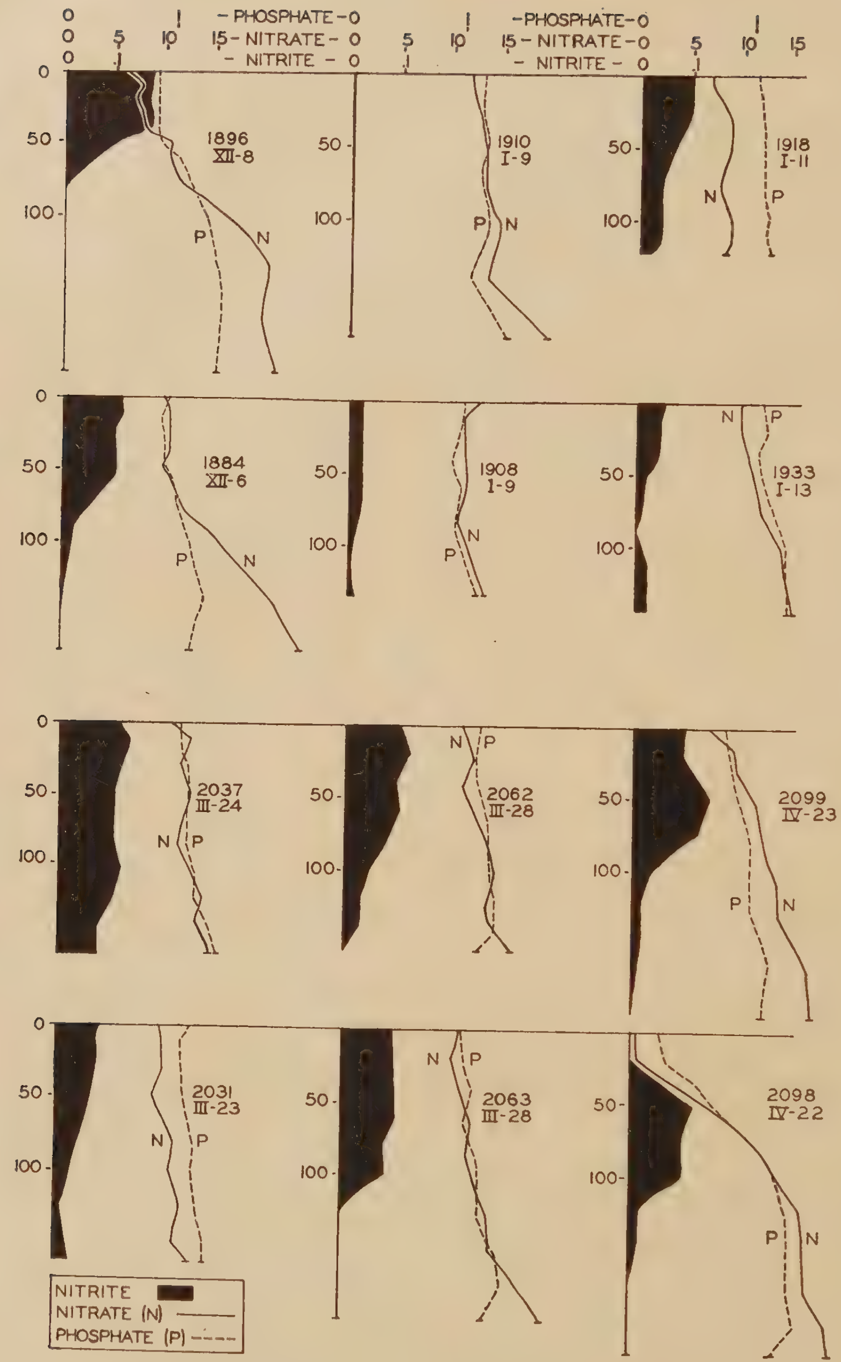

FIG. 9. Relation of nitrite to nitrate and phosphate. Various stations in the Gulf of Maine at different times of year. Ordinates, depths in meters. Positions of stations as follows:

Station	Position	Station	Position	Station	Position
1896	42°48′N 67°15′W	1910	42°43′N 69°15′W	1918	43°39′N 66°39′W
1884	43°00′N 68°37′W	1908	42°10′N 69°53′W	1933	41°25′N 69°02′W
2037	43°58′N 68°03′W	2062	42°44′N 68°44′W	2099	42°22′N 68°32′W
2031	43°18′N 69°23′W	2063	42°31′N 68°31′W	2098	42°50′N 67°19′W

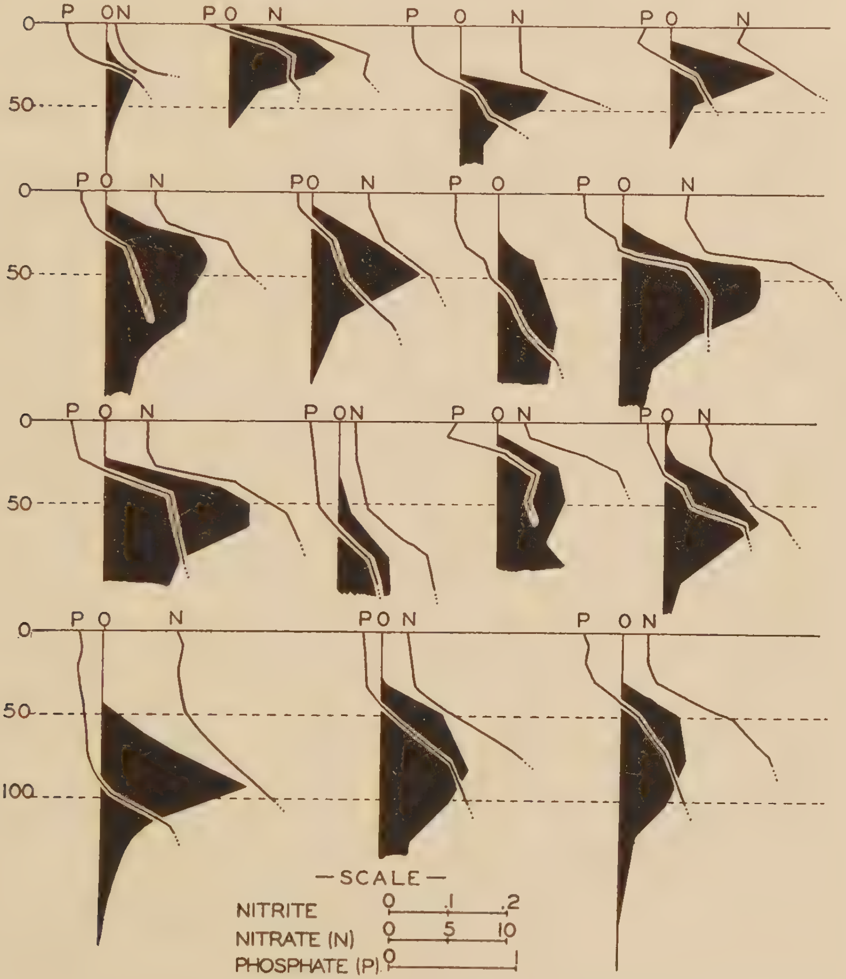

Fig. 10. Relation of nitrite to nitrate and phosphate. Various stations in the Gulf of Maine in the summer. (The origins for nitrite and nitrate coincide, but the phosphate curves are arbitrarily displaced to the left, to facilitate comparison of all three.) Ordinates, depths in meters.

afforded by Schreiber (1927), Cooper (1933), ZoBell (1935) and others.

But the Gulf of Maine is a rather specialized area; let us turn to the open ocean. Similar relations between nitrite, nitrate and phosphate are shown in Fig. 11 for a number of deep sea stations from Latitude 12 to 42 N. Most of these show a clearly-defined nitrite maximum, at about 100 meters, but all show nitrite at the surface, except the three northern stations, which were visited during the summer. At most of them there is a small but distinct amount of nitrite below 150–200 meters. Two stations, 1482 and 1491, are somewhat exceptional. At these, nitrite concentrations are rather low, but extend further down, with no well-defined maximum. The fertility of a region is obviously concerned in nitrite production and these stations are on the edge of the barren Sargasso Sea. Other stations in the Sargasso, as shown in Table IX, are largely devoid of nitrite.

Nearly all the nitrite formation takes place well above the level of maximum nitrate and phosphate concentration, which is found at about 800 meters south of the Gulf Stream and 400 meters north of it.

Density and Temperature

Figure 12 shows the relation between nitrite, density and temperature at stations in Location 9 at various times of year. It can readily be seen that:

1. As the inflection point in the density curve moves further down nitrite moves down also. This is another clear evidence that nitrite is formed near the surface and diffuses or mixes downward, more completely the more unstable the water column.

2. The production of nitrite goes on even at low winter temperatures, but with the rise in temperature nitrite is utilized as diatoms begin to grow.

3. The occurrence of a sharp nitrite maximum coincides with a high density gradient. If the depletion of nitrite above this is the result of diatom activity, this is localized and intensified by strong stratification.

Ammonia

Unfortunately, it was not possible to include simultaneous determinations of ammonia with those of nitrite and nitrate throughout this study. A few such determinations were made, however, using the method described by Krogh (1934). The results are shown in Table X, correlated with nitrite and nitrate. The low values for all three at the surface of Station 1739, and their increase toward the bottom, lend support to the view that they are all utilized at the surface and that ammonia is oxidized to nitrite and nitrate below. The increase of ammonia at the surface of Station 1742 (in Location 22) in September would seem to indicate that organic decomposition is going on more rapidly at this time, and ammonia being liberated, but that the second stage—appearance of nitrite—has not yet been reached. Or it may be that late in the summer, although nitrite is still being utilized, the ammonia is not drawn upon as a nutrient source. This was Cooper's assumption on finding the same condition in the English Channel.

Table X

Relation of nitrite to ammonia and nitrate. Concentrations in microgram atoms per liter.

Station	Depth in meters	Nitrite	Ammonia	Nitrate
1734 7/28/33	77	.01	.4	1.1
	340	0	.3	4.6
	855	0	.3	19.5
	2650	(0)	.6	20
	3280	(0)	.4	
	3725	(0)	.3	20.5
	4180	(0)	.6	23
1739 7/31/33	0	0	1.2	1.1
	10	0		1.1
	20	.02	1.4	2.5
	30	.44		4.0
	40	.39	4.3	5.7
	50	.36		5.7
	60	.24	4.1	7.1
	75	.36	4.3	6.4
1742 9/3/33	0	0	—	1.1
	10	0	2.8	0
	20	.085	3.0	2.1
	30	.15	3.2	4.3
	40	.165	3.2	6.1
	50	.18	3.8	7.5
	60	.185	4.2	7.1
	75	.185	—	7.5
2312	15	.04	.8	>13
	200	.05	0	10
2313	15	.02	.8	6.4
2314	15	.05	.7	2.8
2315	5	.08	.7	1.4
2316	5	.065	0	1.8
2317	5	.065	.3	1.7

At the various depths at Station 1734 the ammonia and nitrite are practically constant throughout, but the nitrite varies widely. From Station 2312 to 2317 the nitrate progressively diminishes, but both nitrite and ammonia are approximately constant. In fact, throughout all the data shown the nitrite is more closely related to ammonia than to nitrate.

Unpublished data in the hands of Dr. A. C. Redfield, on the distribution of ammonia in the Gulf of Maine in May and June, show a distinct tendency for ammonia to concentrate between 20 and 50 meters in a maximum zone similar to that for nitrite.

Nitrite Changes in Stored Samples

A number of previous investigators have tried to determine what happens to the nitrite in samples on standing. The results are altogether irregular and confusing. Buch (1923) reported the formation of as much as 28 mg./cu.m. of nitrite-N in two days, in samples standing in the dark. Harvey noted the appearance of nitrite in a few cases. Orr found increases in nitrite in diatom cultures, even after the diatoms had stopped growing. Braarud and Klem cite some experiments on nitrate reduction, but are not specific as to the relation of nitrite. Cooper followed 44 samples for 10–13 days, to some of which nitrite and ammonia had been added. He reports: " In all cases the changes in nitrite were small, little more than the experimental error." Keys, Christensen and Krogh (1935) followed the ammonia (and in a few cases nitrite, nitrate and oxygen) in samples stored for several days. Results were so variable that they finally conclude: " It appears to us that the only conclusion that can be drawn with regard to nitrogen metabolism in stored sea water is that there are usually a number of forces at work, some operating to reduce the free ammonia, others tending to release ammonia; the observed ammonia will always be a resultant of these forces. . . ."

Although with little hope of clearing up this confusion, a number of similar determinations on stored samples were made. The first of these were simply repeated analyses of the ordinary routine station samples made after a number of days standing. No particular precautions were taken to keep the samples in the dark, but they were exposed to probably less than normal illumination. Nearly 300 samples were followed in this way, with the results shown in Table XI.

One section of the table concerns samples which were originally " nitrite-free," or in which the initial concentration was not greater than .01. These are separated into three periods of standing, approximately 1, 2 and 3 weeks. Those which showed a significant increase in nitrite in that time (greater than .035 microgram atom per liter) amounted to 11 per cent, 12 per cent and 33 per cent of the totals. These 162 samples include many from the surface, with low nitrate, and many from deep levels, with high nitrate. There was no difference in the behavior of these two classes, a fact which has a bearing on the question of reduction of nitrate to nitrite.

The other group of 178 samples contained initial concentrations of nitrite from .01 to .91. Changes took place in both directions. But relatively fewer cases of increase, and more of decrease, were found as the time of standing lengthened. The predominating tendency under these conditions is for nitrite, if initially present, to disappear on standing. If initially absent, it may appear in small amounts.

TABLE XI

Nitrate changes in stored samples

A. Samples with initial concentration = 0 (<.01 microgram atoms per liter)

	5–7 days	12–15 days	20–24 days
Total number	109	41	12
No. increased >.035 microgram atom per liter	12	5	4
Percentage of total	11%	12%	33%

B. Samples with initial concentration >0 (.01–.91 microgram atom per liter)

	5–7 days	12–15 days	20–24 days
Total number	119	25	34
No change (Increase or decrease <10 per cent of initial concentration)	49	9	9
Number increased, over initial concentration, 10–50 per cent	18	1	1
Number increased, over initial concentration, >50 per cent	11	1	0
Number decreased, of initial concentration, 10–50 per cent	31	14	17
Number decreased, of initial concentration, >50 per cent	10	0	7
Percentage of total number which *increased* more than 10 per cent of initial concentration	24%	8%	3%
Percentage of total number which *decreased* more than 10 per cent of initial concentration	34%	56%	70%

The results of these experiments do not lead to a conclusion much more definite than that of Keys, Christensen and Krogh.

Subsequently, however, several series of more carefully controlled experiments were carried out. Samples of filtered surface water were placed in Pyrex flasks. Some of these contained added amounts of ammonia-nitrogen, others added nitrate. Half the samples were sterilized in an autoclave, and of the total number, half were stored in the dark and half were placed in the sunlight as much as possible during the period of storage. Analyses for nitrite were made at intervals up to 19 days. Two series of experiments of this sort were carried out, with the following results:

1. The samples stored in the dark, whether sterile or not, showed no significant change in nitrite, even in the presence of added nitrate or ammonia.

2. Those kept in the light invariably showed a change in nitrite. If it was high at the beginning it decreased, but not so sharply in the presence of excess nitrate. If the nitrite concentration was low at the start it increased slightly, but *more* so in the presence of added nitrate. In fact, after 19 days the nitrite reached the same value, whether by increase or decrease. This seems to depend, however, upon the presence of sufficient nitrate, and is independent of the concentration of ammonia. The conditions surrounding the attainment of this apparent " steady state " will be the subject of further investigation.

3. The rate of disappearance of nitrite was unaffected by the presence of excess ammonia, and only a very slight increase was found in samples of low original nitrite content. In view of the conditions of these experiments this result is not necessarily in conflict with those of ZoBell (1933), who reported the photochemical oxidation of ammonia to nitrite under certain conditions.

4. An effort to follow the changes in nitrate led to inconclusive results. In one series of experiments the sum of nitrite and nitrate (determined by Harvey's " nitrate " method, using reduced strychnine as a color reagent) remained constant, although the concentration of nitrite alone decreased considerably; but in another series the increase in nitrate did not compensate for the disappearance of nitrite.

Thiele (1907) was apparently the first to show that nitrate can be reduced to nitrite by ultraviolet light. Moore (1918) found that sunlight can accomplish the same result, but that the shorter wave-lengths are the most active. More recently, Villars (1927) has studied the photochemical decomposition of KNO_3 in considerable detail and has shown that wave-lengths less than 3,000 Ångstroms are effective in the reduction. About 1 per cent of the total energy of the solar spectrum at sea level falls within this range.

Nitrite in the Sea Bottom

It is evident that at shallow stations, at least, a great part of the decomposition of organic matter takes place on the bottom. A study of the nitrite content of bottom sediments might therefore be significant

Brandt gives figures for the ammonia and albuminoid-nitrogen content of " bottom water " (that in contact with the bottom surface) and of " interstitial water " (that contained in the bottom cores brought up) showing from three to five times as much in the latter as in the former. This relation was apparently independent of depth, for the bottom samples varied from 45 to 3,000 meters. He also cites determinations on muds from the North Sea showing 2–4 mg. of ammonia-N and 5–10 mg. of nitrate-N per kilogram of moist mud.

A number of bottom samples were obtained from various sources and determinations made of the nitrite and nitrate in the interstitial and adjacent water. The results are contained in Table XII.

Figures are given for the nitrite and nitrate not only in the bottom samples, but also in the lowest water bottle, which will vary from 2 to 20 meters from the bottom.

Care must be taken in comparing the results, for different methods were used in obtaining and treating the samples. In some cases, the interstitial water was removed from the whole mud core by suction and the nitrite concentration expressed in terms of the volume of water thus recovered. In other cases, samples of mud and the water in contact with it were collected, either in the coring device, the Pettersson grab, or a special mechanism which sucks up a sample of mud and water off the bottom. Nitrite was determined in this water, after filtration.

Although the data from deep stations are fragmentary they are sufficient to show that conditions in deep bottoms are different from those in shallow ones. The single determination at Station 1731 is not quantitative, but it at least shows that there is very little nitrite in the mud, compared with Stations 1331, 2220 and 2227, where similar technic was used. The condition of the sample from Station 1734 is doubtful, but it should approximate those from A-8 and A-25. Nevertheless, the content of nitrite is very low, and the nitrate is very little greater than that in the lowest water-bottle.

The results from Stations 2220, 2224 and 2227 are interesting in showing the enormous quantities of nitrite in the interstitial water of shallow bottoms.

A comparison of these quantities with those in the supernatant " bottom water " shows that the rate of nitrite formation in the mud is very much higher than its rate of diffusion into the surrounding water.

At Station A-8 and again at A-25 two samples were obtained as close together as possible. The variation in their nitrite and nitrate content is partly due to the method of sampling, which affords a mixed sample of mud and water sucked off the bottom. Nitrite was determined in such a sample after filtration, and although this contains " in-

TABLE XII

Nitrite and nitrate in the sea bottom. Concentration in microgram atoms per liter.

Station	Depth in meters	In lowest water-bottle		In bottom		Method of obtaining sample for analysis
		Nitrate	Nitrite	Nitrate	Nitrite	
1734	4630	20.5[2]	0?	23.0[1]	.05	Water-bottle closed on bottom; brought up mud and water.
1731	3840				.04	Portion of core extracted with surface water.
1336	65	5.0	.28	25.0	1.8	Water brought up with sand in Pettersson grab.
1331	200		.115		.63	Portion of core extracted with surface water.
2220	218		.04		.065	Supernatant "bottom water" on top of core.
2220	218		.04		28.3[3]	Interstitial water removed from core by suction.
2224	195		0		.035	Supernatant "bottom water" on top of core.
2224	195		0		3.3	Interstitial water removed from core by suction.
2227	210		.01		.035	Supernatant "bottom water" on top of core.
2227	210		.01		10.8[4]	Interstitial water removed from core by suction.
A-8*	32	A B	.235 .235	4.6 10.3	.26 .74	The sampling device sucks up a sample of mud from the surface of the bottom, along with water in and around it. Contains interstitial and bottom water in varying proportions.
A-25*	45	A 10.3 B 10.3	.13 .13	17.2 24.6	.20 .25	
Near K-3†	15	A B C			.065 .12 .285	
Near K-3*	15	A B			.75 .77	

* Two samples, A and B, taken as close together as possible.

† Three samples, A, B, C, taken as close together as possible.

[1] Ammonia-nitrogen concentration, 0.65.

[2] Ammonia-nitrogen concentration, 0.35.

[3] Total extractable nitrite-N, 1.5 mgm. per kgm. of dry mud.

[4] Total extractable nitrite-N, .25 mgm. per kgm. of dry mud.

terstitial" and "bottom" water in varying proportions the irregularity of results would nevertheless seem to indicate great local differences in bottom conditions.

Similarly, near Station K-3, three samples were taken simultaneously at one place and two at another. The first three were quite different in nitrite content, while the latter two were practically identical.

The general conclusion to be drawn is that the decomposition of organic matter on the sea bottom involves oxidation of nitrogen compounds to nitrite and nitrate, and that this process is much more intense on shallow bottoms than deep. Nearly all of the nitrification must have taken place before organic matter reached the bottom in the latter cases.

The samples from near Station K-3 were analyzed again after having stood for one day. The nitrite in three had approximately doubled; in the fourth it had increased 50 per cent. The water from the fifth mud sample had been separated from the mud at the time of the first analysis, and the nitrite in this water had *decreased* 50 per cent after one day. Evidently nitrite is formed rapidly and continuously in the mud, diffusing into the water in contact with it. In the water, however, the nitrite is rapidly destroyed, presumably by oxidation to nitrate.

Samples of white coral mud from Castle Harbor, Bermuda, at a depth of about 5 meters, were extracted by distilled water and surface sea water, respectively. The distilled water extract contained: nitrate, .85; nitrite, 0. The surface water extract contained: nitrate, 15; nitrite, .085. The surface water itself was nitrite-free and contained .7 microgram atom per liter of nitrate-N. The more efficient extraction by sea water shows the same phenomenon of "base-exchange" so common in the extraction of soils.

NITRITE AT THE SURFACE

The question of the occurrence of nitrite in the immediate surface layer seems to merit particular consideration.

The first intimation of irregularity occurred on the section from Cape Hatteras to Bermuda (see Fig. 4). At Stations 1462 and 1463 suspiciously high surface values were obtained. These were traced, apparently, to contamination, and were finally rejected. But later, at Station 1465, there could be no doubt of a fairly high concentration at the surface, with very little immediately below. However, no surface nitrite could be found in the vicinity of Bermuda or at the immediately following stations, except 1469. Between this station and 1472 surface samples were picked up every hour or two, while the ship was in motion, without finding more than a trace of nitrite. The same was true of a number of samples taken up between Stations 1473 and

1475. Much later, six samples taken in the same way between Stations 1730 and 1731 were nitrite-free.

Throughout the Caribbean cruise nitrite was found at the surface at the majority of the regular stations, but at four places where surface samples alone were taken none was found. In all, out of thirty surface samples taken with the ship in motion, detectable traces of nitrite were present in only six, and only once a concentration of more than .01. Whether the occurrence of considerable amounts of surface nitrite in the Caribbean is constant or limited to a certain time of the year (as in the north) cannot be said from the results of this one cruise, but the strange irregularity suggests that special factors—perhaps photochemical—may operate in the immediate surface, a matter which will later be investigated more fully. Highly irregular variations in sur-

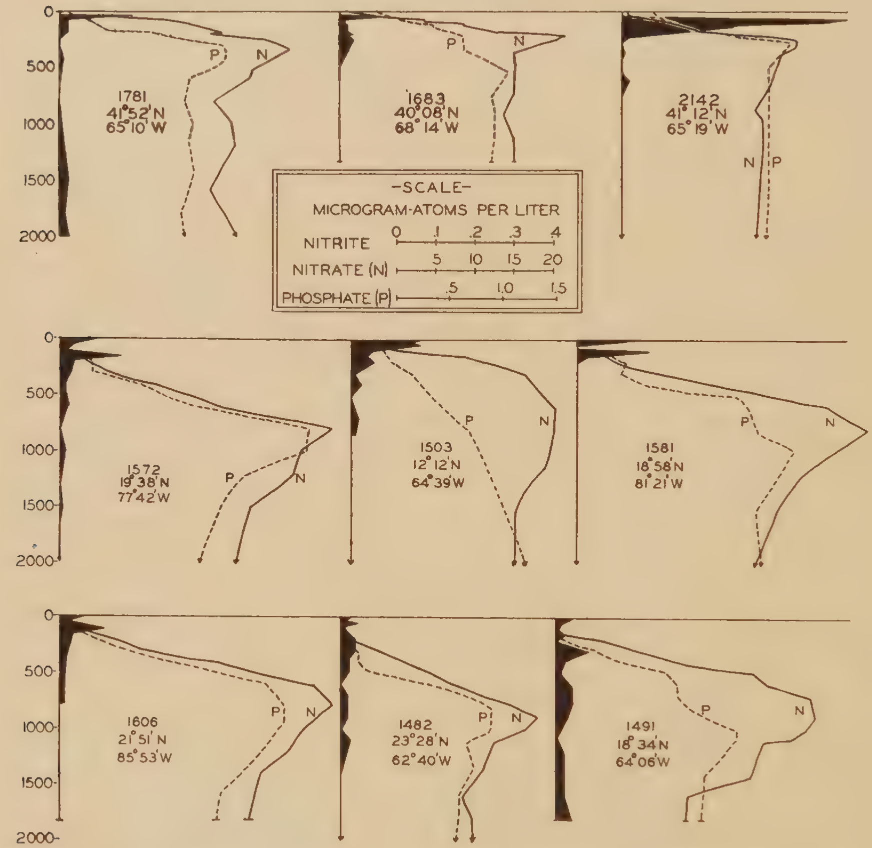

FIG. 11. Relation of nitrite to nitrate and phosphate, at deep stations. Ordinates, depths in meters.

face nitrite have also been reported by Matsudaira and Yasui between Nagasaki and Shanghai.

The vicinity of Bermuda is an area especially devoid of nitrite and other "nutrients." A number of surface samples were collected from the harbors and bays of the Bermuda Islands, and even from their fresh water streams and ponds, with no more than traces of nitrite, and minimal amounts of nitrate.

Seasonal Changes in Nitrite

Figures 5, 6, and 7 contain the data from Locations 3, 5, 7, 8, 15 and 22 in the Gulf of Maine, arranged to show seasonal variations of nitrite and nitrate. Figure 12 shows the progressive changes at Location 9 in a different way. The following points are revealed:

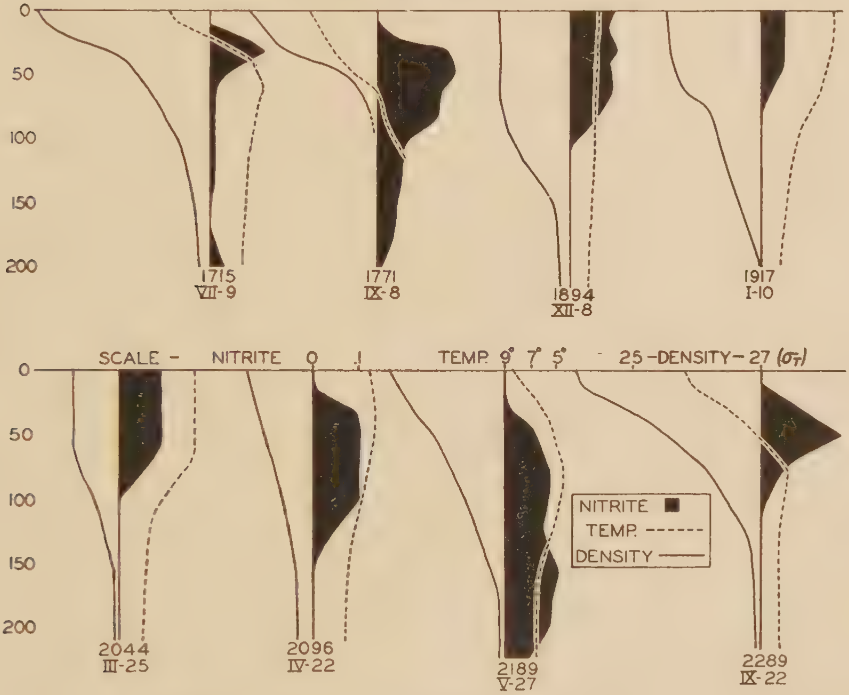

Fig. 12. Relation of nitrite to temperature and density (σ_T). Location 9, Gulf of Maine, at various times of year. Ordinates, depths in meters.

1. A minimum of nitrite occurs in January and February, concentrated at the surface. This corresponds to the period of maximum nitrate and phosphate, when the water mass is nearly homogeneous. Nitrification is going on at the surface, but only very slowly.

2. There follows a slow increase in nitrite until April, when more rapid production accompanies the diatom outburst and continues during the whole period of growth.

3. Simultaneously with the growth of diatoms, however, the removal of nitrate from the surface begins, and nitrite also starts to disappear in the same regions. At Locations 3 and 5 the removal of nitrite lags somewhat behind the nitrate, possibly because the latter is utilized more readily. At Location 7, during July, August and September of the second year, considerable nitrite is still present at the surface, but since the nitrate has not yet been completely used up it would seem that the nitrite store has not been heavily drawn upon.

4. The maximum of nitrite occurs between June and September, varying with local conditions at different stations. There is evidence that the seasons are somewhat displaced in different parts of the Gulf of Maine and that the growth of organisms does not take place uniformly throughout.

5. The utilization of nitrite in the surface layers, simultaneously with its production throughout a much deeper water mass, results in the appearance of a maximum zone, generally between 30 and 50 meters.

6. The occurrence of considerable nitrite in the surface layers at Locations 3, 8 and 15 late in October is noteworthy. This did not occur in all parts of the Gulf but does not seem to be fortuitous. It may well be associated with the death and disintegration of organisms after the close of the growth period. Soot-Ryen reported the same thing in his study of one of the Norwegian fjords. It is possible that this phenomenon was missed at Locations 5 and 7 from lack of data.

7. Location 22, being shallow, shows only the upper part of the picture. Maximum nitrite production has taken place here a little later.

The results of Soot-Ryen are altogether similar to these, with a slight displacement of the seasons. He found a minimum of nitrite in January, increasing through the spring and early summer to a maximum in August, but with depletion of the surface during the summer. This was followed by another short period of nitrite production in the upper layers in November.

Verjbinskaya's data on seasonal variation of nitrite in the Barents Sea are somewhat incomplete, but as far as they go they indicate the same general sequence: nitrite-free water in December and January, building up to a maximum in August, but with surface depletion during the summer.

Cooper's very complete study in the English Channel deals with a station too shallow to show vertical distribution of nitrite, but in all other respects is in complete accord with the above findings. It shows the same simultaneous removal of nitrite and nitrate from the surface in the summer, followed by rapid production of nitrite and ammonia in October, and a minimum during December and January.

No study of seasonal variations at a truly oceanic station seems ever to have been made. Figure 8 shows the nitrite concentration in the upper 1,000 meters of the four corresponding stations in Group 3 (Table V). The only feature in common with the data from shallower stations is the surface depletion during the summer. Nitrite production evidently takes place in the upper levels during the winter. The hydrographic and biological conditions are so different here that a much more complete investigation is necessary.

The Position of Nitrite in the Nitrogen Cycle in the Sea

Brandt, in his monumental work on nitrogen metabolism in the sea, summarized all the earlier results and finally came to the conclusion that ammonium salts are oxidized to nitrite and nitrate by nitrifying bacteria in the sea bottom. Impressed by the fact that such organisms had never been found in the water itself, but that nitrite was frequently present at the surface, he proposed that bacteria might oxidize dissolved organic matter directly to nitrite and nitrate without ammonia as a necessary intermediate.

One view of the significance of nitrite was that expressed by Atkins: that its presence in sea water indicates the production of nitrate. Its absence from deep oceanic samples, on the other hand, shows that nitrification is complete. This assumes, of course, that nitrite is solely produced by oxidation of ammonia, or perhaps from dissolved organic matter directly.

Others, such as Brujewicz (1931) and Braarud and Klem (1931), have rejected this view and incline to that which explains nitrite formation as a result of the reduction of nitrate. Either theory will explain many of the results. Organic matter in the zone of nitrite production, present in considerable amounts, may either be the direct source of nitrite, with ammonia as a likely intermediate, or it may serve as the necessary source of energy for the nitrate-reducing bacteria. These have, in fact, been found there in small numbers.

The presence or absence of the necessary organisms is a bacteriological problem which this present paper cannot go into, but there are a number of considerations from the observed chemical data which favor oxidation as a source of nitrite, rather than reduction.

First, it is unlikely that the upper layers of the water, where oxygen tension is high, would be a suitable environment for reduction processes to take place. The bacterial reduction of nitrate to nitrite is known to be possible under nearly anærobic conditions, and in the presence of enormous quantities of organic matter, but it is not certain that the same thing would take place in surface sea water.

The relation of nitrite and nitrate in bottom muds to each other and to the surrounding water, mentioned above, makes it clear that both are being *formed* in the bottom, obviously by oxidation of organic matter. Since nitrite is an intermediate in this process, it is scarcely possible that the large amounts found here could have been produced by a *subsequent* reduction of the nitrate; and if the nitrite in shallow muds is the result of oxidation it is very likely that all in the water above is of the same origin, for there is no evidence of any discontinuity of chemical mechanism from top to bottom. A comparison of the profiles of stations of varying depths suggests that the concentration of nitrite depends on a balance between the rate of chemical transformation and the rate of descent of the matter being transformed.

The relation between ammonia and nitrite which Cooper's results bring out, as well as the data presented above, especially the increase of both immediately after the summer growth period, are best explained on the assumption of oxidation of the former. The correspondence of the intermediate maximum zone of both nitrite and ammonia, already referred to, supports this view.

The general correlation of low concentrations of both ammonia and nitrite in the deep sea, and of higher concentrations of both, frequently, in other regions, is of some significance.

Furthermore, dissolved organic matter is nearly as abundant at great depths as near the surface, and nitrate is present in large quantity. This would seem to be an optimum condition for reduction of nitrate; but nitrite is seldom found here. It may, of course, be true that dissolved forms of organic matter are unsuitable for nitrate-reducing bacteria.

Finally, the following theory is presented to explain the observed facts:

During the winter, when biological activity is at a minimum, the decomposition of organic matter is going on very slowly. This takes place largely near the surface, either as the result of oxidation of excretory products liberated here, or the death of organisms, with disintegration and decay beginning before they have sunk far. Quantitatively, this same process goes on with greater rapidity as the season progresses. Nitrite is an early stage in the oxidation of this organic matter, presumably after the liberation of ammonia as a previous step. This is in keeping with Wattenberg's (1930) conclusion that ammonia formation is mainly a surface phenomenon. Later in the winter and early spring, as the unstable column becomes deeper, these processes take place through a deeper vertical range.

Still later, when diatoms begin to grow actively they utilize the nitrite in the surface water, along with nitrate. Occasionally, when there are plenty of other nutrients, nitrite is not exhausted. Such is the case in the Antarctic, where determinations made on the "Discovery" show high concentrations of nitrite above 100 meters during the summer, but associated with very large quantities of nitrate and phosphate.

Organic matter works its way downward, by settling, if it is particulate, or by diffusion or mixing, if dissolved. The appearance of nitrite by oxidation therefore extends below the zone of its utilization. At greater depths it disappears again by further oxidation to nitrate.

Nitrate concentration continues to increase to still greater depths, reaching a maximum at 800–1,000 meters, generally. Nitrification extends further than the occurrence of nitrite would indicate.

The decomposition of organic matter takes place in several steps, and we may suppose that the products of the first stages are more rapidly oxidizable than those of the later ones. This may be the result of either the chemical nature of the material or its concentration, which would be greater at the start of the process, before it has become diluted. The formation of nitrite in significant amount is associated with the initial stages of the decomposition of organic matter, probably because of their greater rapidity, but the whole process of nitrification does not complete itself until greater depths are reached, and by this time the nitrite, formed in the first part of the process, has been further oxidized to nitrate.

Vertical differences in temperature may also play a part in determining the rates of decomposition.

Recently, ZoBell (1935) has suggested that diatoms may reduce nitrate to nitrite extracellularly and then absorb it as such. Such a theory would explain many of the observed phenomena with respect to nitrite distribution, to be sure, particularly its close association with phytoplankton. Its acceptance, however, will depend upon its satisfactory explanation of the relation of nitrite to ammonia. Such data as we now have covering this point seem difficult to reconcile with this view, but until we have had an opportunity to extend them we prefer to withold judgment.

ACKNOWLEDGMENT

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Contribution No. 113

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THE REACTIVATION BY CUTTING OF SEVERED MELANOPHORE NERVES IN THE DOGFISH MUSTELUS

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(*From the Woods Hole Oceanographic Institution, Woods Hole, Mass.*[1])

When the melanophore nerves in many lower vertebrates are cut, the areas of skin thus denervated quickly turn dark and remain so for some considerable time. This darkening results from a dispersion of pigment in the melanophores of the denervated areas. Such occurrences were apparently first noted in the common chameleon in 1852 by Brücke, whose observations were confirmed on South African species by Hogben and Mirvish (1928) and by Zoond and Eyre (1934). In bony fishes similar darkenings of the skin as a result of nerve cutting have been recorded by Pouchet (1876), von Frisch (1911), Wyman (1924), Hewer (1927), Giersberg (1930), and Smith (1931), to mention only a few of the more recent workers. Brücke expressed the opinion that melanophores were related to their nerves as muscle-fibers are to motor nerves and that, since the cutting of motor nerves induces paralysis in the neuro-muscular system, the same should be true of melanophore nerves and their effectors. He therefore advanced the idea that severed melanophore nerves with their expanded color-cells are in a state of paralysis. This interpretation of the condition of these parts has been accepted by almost all investigators in this field, even the most recent (Keller, 1895; von Frisch, 1912*a*; Spaeth, 1916; Giersberg, 1930; Zoond and Eyre, 1934; Sand, 1935). In opposition to this view I have advanced the idea that when a melanophore nerve is cut the injury thus inflicted throws the nerve into a state of unusual but temporary activity which may last, however, even for some days. This opinion is based chiefly upon observations on the caudal bands of the common killifish, *Fundulus heteroclitus* (Parker, 1934).

If a dark band is produced by the usual cut in the tail of a pale *Fundulus,* this band, as is well known, will fade out in the course of a few days and become almost if not quite indistinguishable in tint from that of the rest of the fish. If now a second cut is made slightly distal to the first one and within the limits of the original band, a second somewhat smaller band will form between the new cut and the edge of the fin. This second band may be induced at any period after the first band has faded sufficiently and before the degeneration of the melanophore nerves has set in, a disturbance which begins to appear some five days after the initial cut has been made. Any time during these first five days on application of a cold block to such a dark band the part of the band distal to the block may be temporarily obliterated. Or if a cut is made proximal to a block, in a tail in which there is no band, a band will form from the cut to the block but not beyond it, though a cut distal to the block will induce a second band from the new cut to the edge of the tail. These several conditions show that the dark band that immediately results from a cut in the tail of *Fundulus* is not due to the paralysis of the detached portion of the neuro-melanophore system as maintained by almost all previous workers (paralysis hypothesis) nor to the blocking of impulses as suggested by Zoond and Eyre (1934), but is occasioned by the local irritation of the dispersing melanophore nerve-fibers, an irritation that may last for some days (superactivity hypothesis).

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[1] Contribution No. 113.

The situation thus briefly outlined is based upon experiments carried out on *Fundulus*. During the past summer an opportunity was offered at the Woods Hole Oceanographic Institution to apply similar tests to elasmobranchs. The smooth dogfish, *Mustelus canis*, possesses only one set of melanophore nerves, namely, those concerned with pigment concentration. Consequently when a cut is made in the pectoral fin of this fish, a pale band appears in this organ (Parker and Porter, 1934). Such bands disappear in the course of time as the dark bands in *Fundulus* do. If after such a band in a smooth dogfish has faded out (Fig. 1), a second

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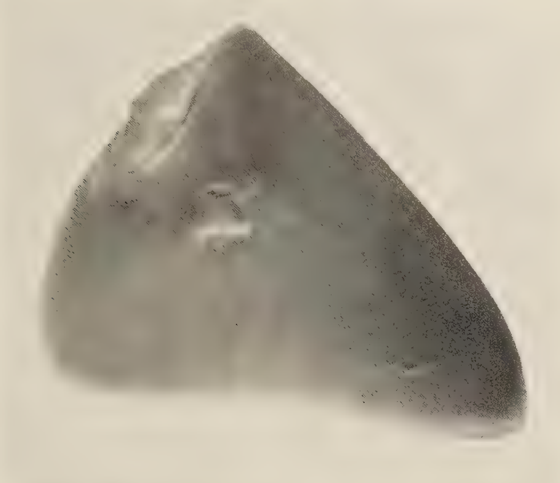
EXPLANATION OF FIGURES

FIG. 1. Right pectoral fin of *Mustelus* seen from above. The initial cut (lower) was followed by the formation of a pale band extending from the cut to the edge of the fin. After this band had darkened as appears in the photograph a second cut was made (upper) proximal to the first one. This second cut produced no observable paleness in the fin.

FIG. 2. Left pectoral fin of *Mustelus* seen from above. The initial cut (upper) induced the formation of a pale band extending from the cut to the edge of the fin. After this band had darkened (Fig. 1), a second cut (lower) was made distal to the first one. This second cut produced the faint splotchy pale area which extends from the region of the cut to the edge of the fin.

FIG. 3. Right pectoral fin of *Mustelus* seen from above. The pale band from the initial cut had darkened before the second cut distal to the first one was made. This second cut excited the formation of a very distinct distal splotch within the area of the former band.



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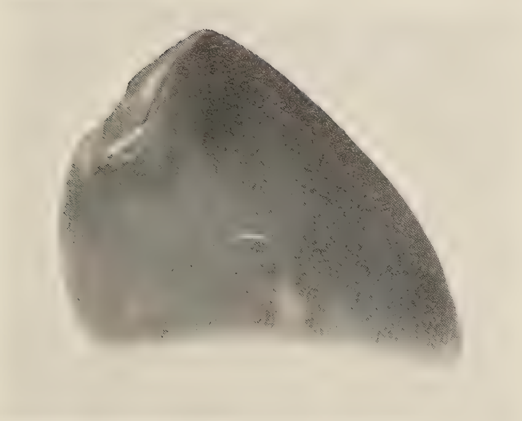

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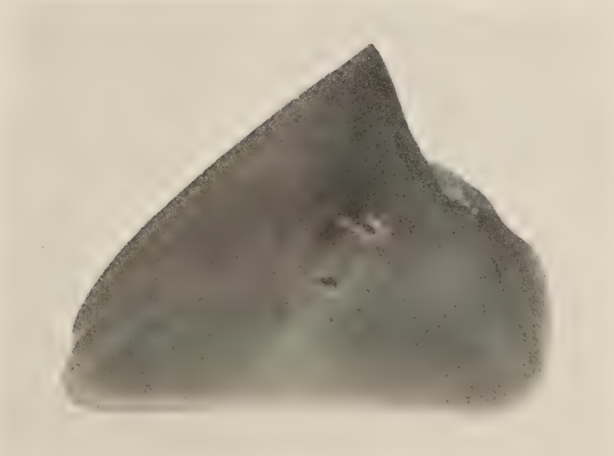

3

FIGS. 1–3

cut is made within the limits of the first one and distal to it, a second fainter band commonly much limited in extent will become visible within the area of the first (Figs. 2 and 3). In *Mustelus* both the primary and the secondary bands are much less regular than in *Fundulus*. This is probably due to the less regular course of the melanophore nerves in the dogfish than in the killifish and to the fact that in the dogfish the one nervous reaction, concentration, is overcome by a humoral response, dispersion, dependent upon a diffuse pituitary neurohumor in the blood. The important point in this discussion, however, is the fact that in *Mustelus* a pale band after it has become dark can be revived by the recutting of its nerves showing that these nerves were not paralyzed by the first cut but remained functional and that the blanching of the band is the result of some form of irritation in the cut and not of paralysis nor of the blocking of impulses. These observations then are in accord with those already reported for *Fundulus* and in this respect support the superactivity hypothesis. Attempts were also made to produce bands in the pectoral fins of the skate *Raja erinacea*, which shows well marked color-changes (Parker, 1933), but the cutting of nerves in the pectoral fins of this fish was not followed by the formation of bands to any observable extent. In this respect *Raja erinacea* is like *Squalus acanthias* in which fin bands are scarcely if at all elicitable (Parker, 1936).

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Contribution No. 114

The Effect of Salinity and Temperature upon the Dissociation of Cresol Red and Phenol Red in Sea Water.

By

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THE desirability of greater precision in measurements of the pH of sea water has been felt by many observers. An approach to this end was presented by Mitchell and Taylor (1) in the form of pK′ values for o-cresol red in various dilutions of sea water at 20° C. and at 30° C. The values were determined for use in colorimetric measurements of sea water pH by the bicolorimeter method. The precision of this method encounters a limiting factor in the inaccuracy of information regarding changes in the dissociation of the indicator with changes in the salinity and temperature of the water sample. If information regarding the behavior of the indicator were sufficiently precise, there should be no difficulty in determining the pH of sea water with an accuracy which would give unquestioned significance to the second place of decimals.

This report confirms and extends the data previously presented for o-cresol red, presents values obtained at 25° C. and also gives values for phenol red in sea water of various salinities at 20° C. and at 25° C.

The use of a constant-temperature room in which the thermostats for the electrodes and for the colorimeter were placed gave more satisfactory temperature control than in the case of measurements previously reported. The procedure was similar in principle to that used by Mitchell and Taylor. Each sample of sea water under observation was diluted with distilled water to varying degrees, giving a series of samples of graded salinity. The original sample and each of its dilutions were then measured with a glass electrode to obtain the pH and were read in the bicolorimeter (Hastings design, Bausch and Lomb model) either immediately before or immediately after the electrode measurement. The glass electrode and its arrangement were as described by MacInnes and Belcher (2). The electrode has a comparatively large tubular surface and the potential

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between it and a saturated calomel electrode is read from a type *K* potentiometer using a Compton electrometer as a null point instrument. The glass electrode potentials were parallel, for standard buffer solutions, to those given by the same solutions with the hydrogen electrode at the same temperature. The electrometer was adjusted to a sensitivity giving approximately 6 mm. of movement of the reflected light along the scale for 0.001 volt. Readings were made to 0.00005 volt. The glass electrode was standardized with buffer solutions of known pH before and after each set of measurements and showed a satisfactory degree of stability of its asymmetry potential. Variations were less than 0.001 volt in the course of a week provided the temperature and the position of the electrode were maintained in a steady state.

In order to reduce to a minimum any changes in the CO_2 tension of the water sample during the time that measurements were being taken, 500 ml. of each sample were mixed with the required amount of indicator solution in a narrow separatory funnel and only the portion in the lower part of it was used for rinsing and filling the glass electrode and the bicolorimeter cups. This precaution was found to be necessary for reproducible results as the respiration of the observer caused a rising CO_2 content of the air of the constant temperature room. Duplication of results, however, was such as to indicate that the CO_2 content of the water was controlled satisfactorily during the taking of a set of measurements. If small samples are to be used some device for transfer of the sample to the colorimeter cup without exposure to air and for keeping the cup closed during measurements would be desirable. A cover for the cup was tried in the form of rubber sheeting perforated to admit the plunger but was found inconvenient to use. In this form of bicolorimeter, however, the cup containing the portion of sample to be observed is only slightly larger in diameter than its plunger so that if a sufficient streaming of the sample through the cup is permitted and the latter is quickly put in place and plunger inserted, satisfactorily reproducible results are obtained. In a series of readings either with the same or with different fillings of the cup extending over a period of 10 minutes the variability of the readings is no greater with diluted sea water of low buffering capacity than it is with a well-buffered standard solution.

The salinity of each sample and its various dilutions was measured by the usual silver nitrate titration.

The pK′ value of the indicator was obtained by subtracting the log. of the ratio of the depth of the standard alkaline solution to the depth of the standard acid solution at the matching point from the pH of the water as obtained by the use of the glass electrode.

$$\mathrm{pK}' = \mathrm{pH} - \log \frac{y - x}{x}$$

where y is the total depth of the two standard solutions and x is the depth of the acid one.

In some of the measurements, however, observations were taken

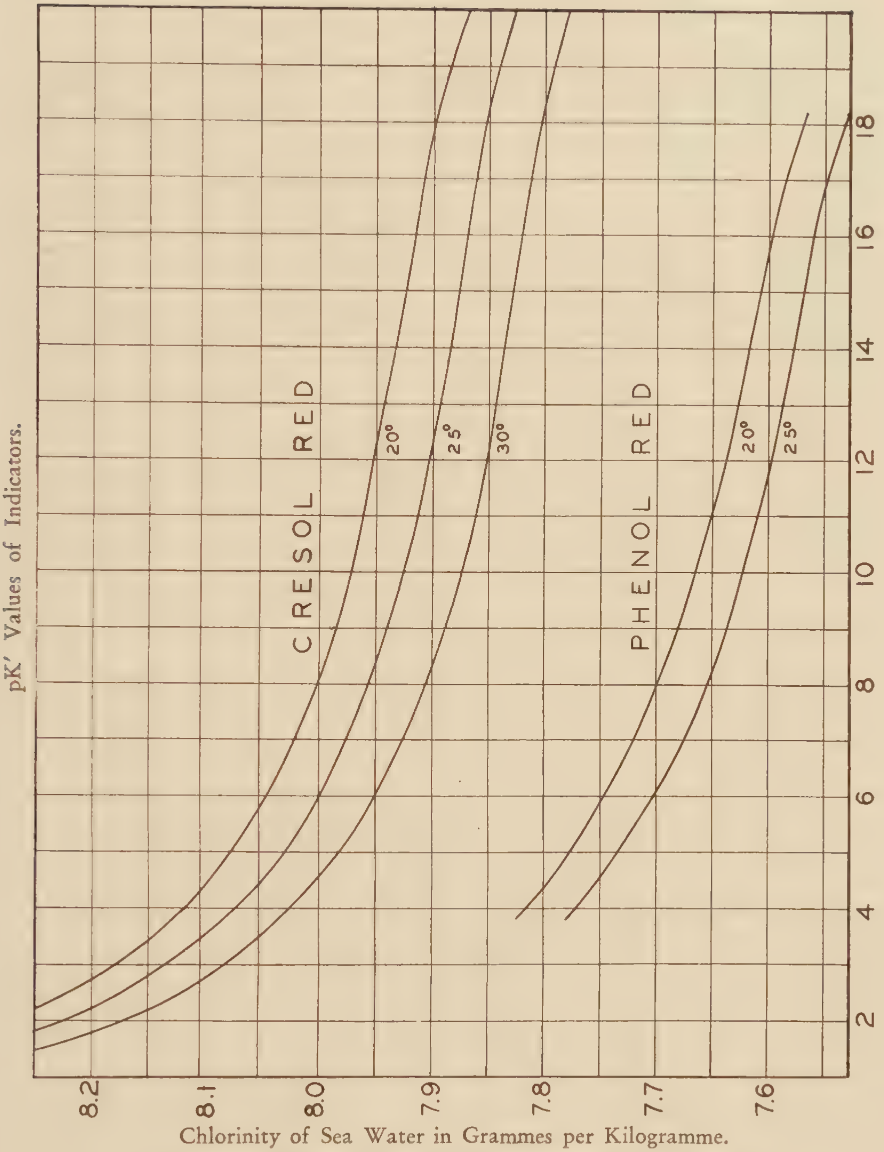

Fig. 1. — The pK′ Values of Cresol Red and Phenol Red as influenced by the salinity and temperature of sea water.

by the colorimetric method of Buch (3) comparing sea water samples containing o-cresol red with Palitzsch standard borate buffer solutions, while the same sea water sample was measured for pH in the glass electrode. In this case the difference between the two results was taken as the "salt error". Values thus obtained, when subtracted from the pK′ value of the indicator as measured in these standard borate solutions gave results in good agreement with those obtained by the use of the bicolorimeter.

Typical results are presented in Tables 1, 2, and 3. Duplicate measurements on the same sample are shown in order to indicate the degree of the probable error of the observations which is approximately ± 0.007. The results are summarized in graphic form in Fig. 1, in which the curve for pK′ of o-cresol red at 30° C. is taken from Mitchell and Taylor (1) for purposes of comparison; the curve for o-cresol red at 20° C. is constructed from a composite of results previously obtained together with the newer data obtained under conditions of better temperature control; and the other three curves represent new measurements only.

Table 1. pK' Values of o-Cresol Red in Sea Water.

Chlorinity of sample		Salinity of sample	Glass electrode result	Bicolorimeter result	pK′
grammes per litre	grammes per kilo	grammes per kilo	pH	$\log \frac{y-x}{x}$	at 20° C
19.50	19.04	34.40	7.868	9.995 — 10	7.873
			7.866	9.991 — 10	7.875
17.42	17.04	30.79	7.803	9.898 — 10	7.905
			7.735	9.840 — 10	7.895
13.48	13.25	23.95	7.699	9.772 — 10	7.937
			7.654	9.712 — 10	7.942
10.03	9.90	17.89	7.652	9.672 — 10	7.980
			7.607	9.636 — 10	7.971
9.91	9.79	17.70	7.983	9.998 — 10	7.985
			7.985	9.993 — 10	7.992
8.00	7.92	14.33	7.912	9.912 — 10	8.000
			7.914	9.912 — 10	8.002
5.89	5.85	10.59	7.809	9.766 — 10	8.043
			7.793	9.773 — 10	8.020
4.00	3.98	7.21	7.504	9.350 — 10	8.153
			7.450	9.325 — 10	8.125
					at 25° C
18.20	17.79	32.14	7.780	9.947 — 10	7.833
			7.779	9.915 — 10	7.864
17.67	17.27	31.20	7.908	0.058	7.850
			7.908	0.052	7.856
16.18	15.85	28.64	7.939	0.090	7.849
			7.941	0.078	7.863
13.72	13.50	24.41	7.940	0.041	7.899
			7.938	0.037	7.901
12.14	11.96	21.62	7.905	9.994 — 10	7.911
			7.905	9.994 — 10	7.911
8.18	8.10	14.65	7.825	9.852 — 10	7.973
			7.823	9.860 — 10	7.963

Table 2. pK' Values of Phenol Red in Sea Water.

Chlorinity of sample		Salinity of sample	Glass electrode result	Bicolorimeter result	pK'
grammes per litre	grammes per kilo	grammes per kilo	pH	$\log \frac{y-x}{x}$	at 20° C
17.84	17.43	31.49	7.973	0.404	7.569
			7.985	0.404	7.581
16.16	15.86	28.66	8.005	0.396	7.609
			8.004	0.396	7.608
14.07	13.83	24.99	7.976	0.355	7.621
			7.970	0.348	7.622
12.07	11.89	21.49	8.000	0.355	7.645
			7.976	0.348	7.628
10.37	10.25	18.53	8.051	0.396	7.655
			8.000	0.328	7.672
10.06	9.94	17.79	7.941	0.268	7.673
			7.935	0.266	7.669
8.14	8.06	14.58	8.002	0.288	7.714
			7.987	0.266	7.707
5.94	5.90	10.68	7.943	0.158	7.785
			7.890	0.146	7.744
3.93	3.91	7.09	7.663	9.854 — 10	7.809
			7.673	9.847 — 10	7.826
					at 25° C
18.20	17.79	32.14	7.921	0.381	7.540
			7.912	0.381	7.538
16.25	15.84	28.62	7.879	0.320	7.559
			7.944	0.382	7.562
14.03	13.78	24.90	7.950	0.371	7.579
			7.944	0.368	7.577
12.17	11.99	21.67	7.942	0.343	7.599
			7.939	0.341	7.598
10.34	10.21	18.45	7.725	0.114	7.611
			7.736	0.111	7.625
8.35	8.27	14.96	7.630	9.976 — 10	7.654
			7.624	9.976 — 10	7.648
6.25	6.21	11.24	7.531	9.830 — 10	7.701
			7.517	9.823 — 10	7.694

Table 3. "Salt Correction" for o-Cresol Red in Sea Water at 20° C. to be used in connexion with the buffer solutions of Palitzsch.

Sample No.	Chlorinity of sample	Salinity of sample	Glass electrode result	Colorimetric result	"Salt Correction"
	grammes per kilo	grammes per kilo	pH	pH	
1	17.54	31.69	7.941 7.941	8.19 8.18	0.25 0.24
2	11.80	21.33	7.906 7.826	8.115 8.07	0.21 0.24
3	8.90	16.09	7.945 7.945	8.13 8.13	0.185 0.185
4	5.93	10.73	7.946 7.944	8.075 8.075	0.13 0.13
5	3.59	6.51	7.917 7.910	7.97 7.96	0.05 0.05
6	1.80	3.25	8.073 8.015	(8.07) (8.02)	(0.00) (0.00)

To samples 2—5 some sodium carbonate was added so that these had the same titration alkalinity as no. 1. Sample no. 6 was made from no. 5 by dilution. The result of no. 6 is to be considered as somewhat less accurate than the others. All values were used for calculating, by the method of least squares, the following equation showing the relation between the salt error and the salinity between 3 and 35 $^0/_{00}$

$$\text{salt correction} = 0.373 - 0.257\sqrt[3]{S} + 0.006 \cdot S.$$

In calculating this equation the increase in salinity — less than 0.1 $^0/_{00}$ — caused by the addition of sodium carbonate, was considered. It is obvious that these corrections can be used only when the buffer solutions of Palitzsch are used as standards.

It is obvious that pK′ values as presented in these curves can be used in practical measurements only if the indicator to be employed is of the same purity and composition as that used for these standardizations. The variability of the behavior of commercial indicators is too well known to require comment. The cresol red and phenol red used for these measurements were from LaMotte Chemical Products Co., purchased as 1 $^0/_0$ solution and diluted with distilled water to 0.02 $^0/_0$ and 0.04 $^0/_0$ respectively. In each case 1 part of the diluted indicator solution was added to 20 parts of the sea water or standard solution. The behavior of the indicators is characterized by the data presented in Table 4.

Table 4. Characteristics of the Indicators Used.

	pK′ in Sørensen M/15 standard phosphate buffers, pH 7.4 – 8.0		pK′ in Clark and Lubs standard borate KCl buffers, pH 7.5 – 8.0	
	at 20° C	at 25° C	at 20° C	at 25° C
o-Cresol red	8.06	8.01	8.17	8.11
Phenol red	7.75	7.72	7.84	7.81

The effect of temperature upon the dissociation of the indicator is seen to be such that a satisfactory estimation of the pK′ of o-cresol red in a solution of given ionic content at temperatures in the neighborhood of 20° C. can be computed by the formula

$$pK'_t = pK'_{20} - 0.01\ (t - 20)$$

where pK′ is the value at the prevailing temperature, *t*, and pK'_{20} is the value in the same solution at 20° C. For phenol red, the formula is

$$pK'_t = pK'_{20} - 0.007\ (t - 20)$$

which is in agreement with values for the effect of temperature upon phenol red as reported by Kolthoff (4). It is thus apparent that the temperature effect upon o-cresol red is greater than it is upon phenol red.

If the values represented by the curves in Fig. 1 are to be used in connexion with measurements of the pH of sea water in a bicolorimeter, it is only necessary to read off the pK′ value of the indicator above the point corresponding to the chlorinity of the sample, interpolating for the temperature effect. But if these values are to be employed in connexion with colorimetric comparison with standard tubes, it becomes necessary to know the pK′ of the indicator in the standard solutions used at the prevailing temperature. From this value the pK′ at the chlorinity and temperature of the water sample is to be subtracted to give the "salt correction".

Summary.

The effect of the salinity of sea water and the effect of temperature upon the dissociation of o-cresol red and phenol red are shown in the form of pK′ values to be used in the colorimetric measurement of the pH of sea water.

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Contribution No. 116

Sampling Variations in the Use of Plankton Nets.

By

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A considerable literature exists relative to the accuracy of quantitative plankton studies based on the use of various types of nets. So far as we have been able to learn, however, there has been very little attempt at a study of the sampling variations actually found. It is our purpose in the present paper to examine the available published data with a view to determining the nature and extent of the sampling variations encountered, so far as this is practicable.

Hensen (1887) discusses the variation to be expected in vertical hauls. He made several series of parallel hauls, with resulting coefficients of variation in the total volume of the catch of the order of 10 to 15 %. Lohmann (1903) made a further examination of this data, and concluded that one may expect variations of 20 to 30 % in the number of organisms of a particular species; but that for certain types the variation may be much greater.

Herdman (1921) carried out a number of similar experiments at Port Erin, taking care to select days and hours when tide and weather conditions were as nearly ideal as possible for making comparable repeated vertical hauls. In seven series of four to six hauls, he found the percentage deviation from the mean number of each class of organisms ranged from 14 % to 121 %. Unfortunately, he does not give details of the individual hauls to permit us to make further calculations with his data, nor does he offer any sampling theory by which the probable error of other plankton hauls can be calculated.

Gardiner and Graham (1925) made a series of 10 oblique hauls with a Petersen's young fish trawl to determine the working error of this apparatus. They calculated the standard deviation, which, expressed in percentage of the mean, varied between 27 % and 54 %. Like Herdman, however, they give no basis for determining the probable error of other hauls.

Gardiner's (1931) study of the international net is perhaps the most elaborate and carefully planned of which we are aware. He concludes that about 75 % of hauls will not deviate by more than 33 % from the mean of a long series; but that isolated deviations may reach

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90 %. He does not give actual catches, but organisms per metre depth, based on "two, or more, separate samples" "in the majority of cases". While we have been unable to use his data in our own computations, we feel that his results are in essential agreement with those which we present below.

In the study of sampling variations, we are interested in the variations occurring in the numbers of organisms caught in hauls made at the same time and place, with the same technique. Ideally, the problem may be stated in terms of an urn schema. We have a container with a very large number of black and white balls, from which we draw samples. We should like to know how the numbers of black balls in successive samples may be expected to vary. The ideal method would evidently be to make a very large number of trials from the same container; but this is impossible, if only because the container (in our case, the particular spot in the ocean) and its contents cannot be expected to remain unaltered over the time necessary to draw our samples. We are therefore forced to draw a limited number of samples from each of a number of different containers. This is not necessarily a disadvantage; in fact, it has some obvious advantages, since in this way we may perhaps eliminate the special peculiarities of one particular locality.

The data we need are, in principle, the numbers of organisms actually caught in each haul; or, where the total catch is not counted, we require the number counted and the fraction that the number counted was of the whole catch. Unfortunately, in many cases it is impossible to determine these figures from actual published data; such cases are of no use for the present study.

Two sets of data have been found which meet our basic requirements. The first of these is a series of counts of fish eggs, made over a period of years (1902—1909) at Heligoland. These we shall refer to as the Ehrenbaum-Strodtmann series. (The individual references are given in the bibliography.) The catches were made with the Hensen egg net; the counts are total counts. The original counts are subdivided by species, but we have used only total eggs, since in most cases a single species predominates heavily.

The second series is taken from an investigation by Künne (1929, 1933) on the relative catching power of different types of nets. The counts here are total counts. The animals counted were of such a size as to preclude the possibility of loss by escape through the mesh of the net. The Hensen net was used throughout as a standard with which other nets were compared. We have accordingly worked up our results largely on the Hensen net; but, as will appear, there seems to be no reason to suppose that other nets differ very markedly from the Hensen net.

The problem of plankton sampling resembles in some respects the problem of estimation of bacterial numbers, especially by the method of plate counting. It therefore seemed possible that the sampling fluctuations in the two cases might be subject to essentially the same laws. In bacterial plate counts it has been shown by Fisher, Thornton, and MacKenzie (1922) that the Poisson distribution gives a good description of the facts in cases where the technique is adequately controlled. We accordingly proceeded to investigate whether the same law might hold here. (For the theory involved, see the Appendix).

For this purpose we computed, for each pair of observations, the quantity

$$\chi^2 = \mathrm{S}\,\frac{(n-\bar{n})^2}{\bar{n}^2} = \frac{(n_1-n_2)^2}{n_1+n_2}\;. \tag{1}$$

If the basic distribution were truly Poisson, this χ^2 should, in a number of random samples, have a mean value $= 1$, and should be distributed in a known manner. We may conveniently test this by making up a frequency distribution of the values of χ^2 found, as shown in Table I .

Table I.

Distribution of values of χ^2.

χ^2	Proportion of cases expected	E. – S.	Künne-Hensen net	Künne-other nets	All nets
0—.016	0.1	34	13	13	60
—.064	0.1	33	13	16	62
—.148	0.1	16	18	19	53
—.275	0.1	19	17	23	59
—.455	0.1	29	24	25	78
—.708	0.1	22	16	13	51
—1.074	0.1	28	25	22	75
—1.642	0.1	32	32	21	85
—2.706	0.1	39	25	29	93
—6.635	0.09	40	47	42	129
over 6.635	0.01	38	44	31	113
	Total cases	330	274	254	858

Notes

(1) Only hauls with $n_1 + n_2 > 9$ are included in the table.

(2) The χ^2 classes have been chosen to give equal expectancies in each class, except the last two.

It is at once apparent that the distribution is very far from the theoretical. There is a great excess of large values of χ^2; which means that there is an excess of samples showing relatively large differences between hauls.

We may inquire whether there is any indication in Table I that different workers, or different nets, may vary in the distribution of their deviations. The three distributions, E.-S., Künne-Hensen, and Künne-other nets, have therefore been treated as a contingency table. The value of χ^2 turns out to be 28.36, with 20 degrees of freedom. The corresponding value of P is very nearly 0.10. There is thus no adequate ground for asserting the existence of differences in the distribution of deviations.

To obtain further light on the nature of the discrepancy, we tabulated the totals of the χ^2 values classified by sample size. Section A of Table II shows the result for all samples obtained with the Hensen net, and Section B the result for all nets. It is clear from this table that the larger hauls furnish more than their share of the high values of χ^2, as indicated by the increase in mean χ^2 with increasing size of sample.

It is thus apparent that the sampling distribution departs from the Poisson in that the differences between hauls are larger than would be expected, and further, that with increasing haul size these discrepancies increase.

This suggests that in addition to the random distribution of organisms, other factors are operative in producing sampling deviations¹). We may then suppose that the variation actually observed is the result of (a) variations in the distribution of organisms and (b) variations in the mode of sampling. Under (b) are to be included such factors as variations in speed of hauling, deviation of the haul from the vertical, completeness of washing of the net, etc. In general, most

Table II.

Values of total and mean χ^2 for hauls of different sizes.

A. Hensen Nets				B. All Nets			
Total catch	Number of pairs	s (χ^2)	Mean χ^2	Total catch	Number of pairs	s (χ^2)	Mean χ^2
9—18	97	166.87	1.720	9—18	155	247.21	1.595
32	90	139.47	1.550	32	125	174.89	1.398
50	79	144.60	1.830	50	110	201.72	1.834
72	65	160.11	2.463	72	83	199.58	2.405
98	67	165.84	2.475	98	84	191.52	2.280
128	36	59.45	1.651	128	47	112.48	2.393
162	41	109.31	2.666	162	49	162.80	3.322
200	22	108.15	4.916	200	34	178.52	5.251
242	28	333.34	11.905	242	37	347.27	9.386
288	9	87.67	9.731	288	16	140.38	8.148
338	17	160.77	9.457	338	23	202.17	8.790
392	11	153.87	13.988	392	14	160.65	11.475
450	13	206.73	15.902	450	14	208.23	14.874
578	15	248.53	16.769	578	23	299.47	13.020
over 578	14	282.38	20.170	722	12	189.43	15.786
				over 722	32	899.07	28.096

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¹) The suggestion for this treatment was derived from Berkson, Magath, and Hurn's (1935) study of chance fluctuations of erythrocyte counts.

of the variations under (b) will be independent of the variations under (a). We can then write

$$\sigma_n^2 = \sigma_P^2 + \sigma_S^2 \tag{2}$$

where σ_n is the standard deviation of the total catch, σ_P the standard deviation which would be observed were there no variation under (b), and σ_S that which would be observed with no variation under (a).

We may further observe that most of the factors to be placed under (b) may be thought of as essentially acting through their effect on the volume of water filtering through the net. If we assume that variation under (b) arises essentially through variations in volume of water sampled, then, as shown in the appendix, we may write

$$\sigma_n^2 = m + m^2 \frac{\sigma_v^2}{\bar{v}^2}$$

where σ_v = standard deviation of volume filtered

$\bar{v}$ = mean volume filtered

m = mean number of organisms which would be caught in a great number of hauls.

This may also be written

$$\frac{\sigma_n^2}{m} = 1 + m \frac{\sigma_v^2}{\bar{v}^2} \; ;$$

or, since our best estimate of $\frac{\sigma_n^2}{m}$ is given by χ^2, and of m is $\frac{n_1 + n_2}{2} = \bar{n}$, we have finally

$$\chi^2 = 1 + \bar{n} \frac{\sigma_v^2}{\bar{v}^2} = 1 + K^2 \bar{n} \cdot \tag{3}$$

In Fig. 1 the mean values of χ^2 from Table II have been plotted against $\bar{n}$. It is at once clear that the points are far too irregularly distributed to determine the value of K^2 with any precision. We have actually drawn a line which gives K^2 a value of 0.05; but anything between $K^2 = 0.04$ and 0.06 would give nearly as satisfactory a fit.

If we accept $K^2 = 0.05$ as a reasonable approximation, the standard deviation of a single observation is

$$\sigma = \sqrt{n + .05\, n^2} \tag{4}$$

and the coefficient of variation, which we take as a measure of the relative accuracy of estimate, is

$$\frac{\sigma}{n} = 100 \sqrt{\frac{1}{n} + .05}\,. \tag{5}$$

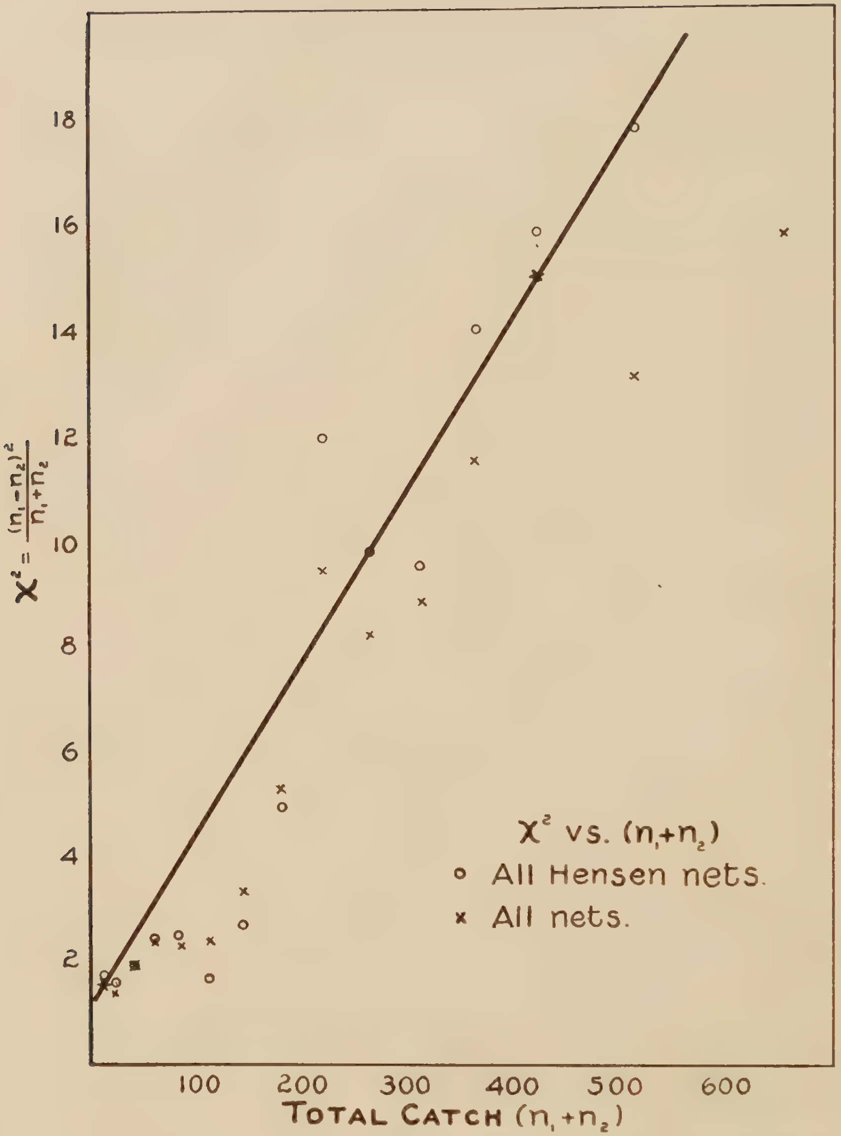

Fig. 1. Distribution of mean values of χ^2 for hauls of varying size.

The last expression, we may observe, implies that for large hauls, the relative accuracy of a single haul will approach about 22.5 %[2]).

---

[2]) We have chosen to express relative accuracy in terms of the ratio of standard deviation to mean. If the ratio of probable error to mean is preferred, our figures for percentage accuracy should be multiplied by 0.6745. We are unable to see any advantage in the use of the probable error.

In cases where more than one haul has been made at a station, the accuracy with which the mean is known is given by the familiar formula

$$\sigma_m = \frac{\sigma}{\sqrt{N}} \qquad (6)$$

where σ_m is the standard deviation of the mean, σ the standard deviation of a single haul, and N the number of hauls. Thus if we have a single haul which has given 100 organisms, the relative accuracy attaching to this is about ± 24.6 %. If we had two such hauls, our relative accuracy would be increased to about ± 17.3 %.

All that has been said thus far applies to complete counts. If only a fraction of the haul is counted, it is clear that an allowance will have to be made for variability arising from laboratory sampling. If we actually count a fraction p of the total catch, our estimate of the total will be

$$n' = \frac{c}{p}$$

where c is the number counted. Now a number of such estimates made on a single haul will have standard deviation

$$\sigma_{n'} = \frac{\sigma_c}{p} \; ;$$

but we have to take account also of the variability of the hauls themselves. As shown in the appendix, this results in an expression

$$\sigma_{n'} = \frac{1}{p}\sqrt{K^2c^2 + c} \qquad (7)$$

for the standard deviation of n'; and for the coefficient of variation of our estimate we have

$$\frac{\sigma_{n'}}{n'} = 100\sqrt{K^2 + \frac{1}{c}} \; . \qquad (8)$$

We observe that this expression is of exactly the same form as that previously obtained for the case where the whole catch was counted, except that on the right-hand side the number actually counted appears.

We may therefore conclude that it is useless to count more than such a number of organisms as will make the fraction $\frac{1}{c}$ small relative to K^2. In practice, if K^2 is, say, 0.05, a count of 100 organisms gives $\sigma_{n'}/n' = 0.245$, while a count of 1000 reduces $\sigma_{n'}/n'$ only to 0.226. It therefore appears useless to increase the number counted of a particular type much above 100.

It may equally be observed that if the number counted falls much below 100, the relative accuracy rapidly decreases. For the particular value $K^2 = 0.05$, we have calculated Table III, both for single hauls and for paired hauls. In the case of paired hauls, the "number counted" is the mean of the separate counts.

To avoid misconceptions, we may emphasize that the particular value $K^2 = 0.05$ which we have chosen is not to be regarded as a universal constant. We have chosen it because it seems to give a reasonable fit to the data available to us; but we have no doubt that its value will vary from one worker to another, and from one set of conditions to another.

Table III.

Number counted	Coefficient of variation of estimated catch, single hauls	Coefficient of variation of estimated catch, paired hauls
1	102.5	72.5
5	50.0	35.3
10	38.8	27.4
25	30.0	21.2
50	26.5	18.7
75	25.2	17.8
100	24.5	17.3
∞	22.4	15.8

Summary.

The published data have been examined with a view to determining the sampling variability inherent in the use of plankton nets. The dispersion found is greater than can be attributed solely to random dispersal of the organisms in the medium. It is found that if variability is assumed to arise from two sources, (a) random dispersal of organisms and (b) variations in volume of medium sampled, the observed results are reasonably well accounted for. On this assumption it is shown that a limit to the precision of estimate is set by the relative variability of the volume sampled. As a corollary, it appears that it is useless to increase the count of organisms of any particular type much beyond 100.

Appendix

Derivation of Formulae.

1. Poisson distribution.

Assume plankton organisms of some definite type distributed at random with a mean density M. Let the volume of one of these organisms be v, and let the total volume sampled be V. Then this total volume may be divided into $N = V/v$ units of volume. The probability that a particular one of these units shall be a plankton organism is then

$$p = Mv = \frac{MV}{N}$$

The probability of catching exactly n organisms is

$$P(n) = \frac{N!}{n!\,(N-n)!}\,p^{n}\,(1-p)^{N-n} = \frac{N!}{n!\,(N-n)!}\left(\frac{MV}{N}\right)^{n}\left(1-\frac{MV}{N}\right)^{N-n} \qquad (1)$$

Now if N is large compared with MV, so that p is small, a close approximation to (1) is given by

$$P(n) = \frac{e^{-MV}\,(MV)^{n}}{n!} \qquad (2)$$

This is the well-known Poisson exponential limit to the binomial.

The mean and standard deviation of a population distributed according to (2) are:

$$\text{mean} = m = MV$$

$$\text{s.d.} = \sigma = \sqrt{MV}$$

In practice, we have only samples, and we wish to know whether they might reasonably have been drawn from a population distributed according to the Poisson law. This problem has been analysed by Fisher, Thornton, and MacKenzie (1922), whose treatment we shall follow here.

Consider k samples, of sizes $n_1, n_2, \ldots, n_k$, of which the mean is $\bar{n}$. The probability of obtaining such a series from a population distributed according to (2) is

$$P(n_1, n_2, \ldots n_k) = \frac{e^{-kMV}\,(MV)^{k\bar{n}}}{n_1!\,n_2!\,\ldots n_k!} \qquad (3)$$

This may also be written

$$P(n_1, n_2, \ldots n_k) = \frac{e^{-kMV}\,(kMV)^{k\bar{n}}}{(k\bar{n})!} \cdot \frac{(k\bar{n})!}{n_1!\,n_2!\,\ldots n_k!\,(k)} \qquad (4)$$

in which the first factor on the right is the probability of obtaining a set of k samples having a mean $\bar{n}$, and the second factor is the probability that k samples with a mean $\bar{n}$ shall have the values n_1, n_2, $\ldots$ n_k actually observed. That is,

$$P(n_1, n_2, \ldots n_k) = P(\bar{n}) \cdot P_{\bar{n}}(n_1, n_2, \ldots n_k) \qquad (5)$$

$$P(\bar{n}) = \frac{e^{-kMV}\,(kMV)^{k\bar{n}}}{(kn)!} \qquad (6)$$

$$P_{\bar{n}}\,(n_1, n_2, \ldots n_k) = \frac{(kn)!}{n_1!\,n_2!\,\ldots n_k!\,(k)^{kn}} \qquad (7)$$

Now we may observe, first, that from (6) it follows that our best estimate of MV is given by $\bar{n}$; and second, that the probability of a given partition of an observed $\bar{n}$ is independent of the value of MV. Now the quantity

$$\chi^2 \quad \frac{1}{n}\, S\, (n-\bar{n})^2 \qquad (8)$$

is a measure of the departure from equipartition of the observed values $n_1, n_2 \ldots$; and the distribution of χ^2 is known, and depends only on the number of degrees of freedom. Tables giving the probability of occurrence of values of χ^2 for different numbers of degrees of freedom have been published (Pearson, 1914; Fisher, 1925). Further, the χ^2 distribution has the property that the sum of a number of χ^2 values is distributed as χ^2, with degrees of freedom equal to the sum of the degrees of freedom of the components.

This latter point is of great importance to us, because in practice it is difficult to obtain more than a limited number of parallels from any one locality. The additive property of χ^2 enables us to combine results obtained by sampling in different localities. We can thus test whether it is reasonable to suppose that a series of sets of parallels have been drawn under Poisson conditions, the Poisson parameter being supposed variable from set to set, though constant within each set.

Actually, we deal here with sets of two parallel hauls. The formula for χ^2 then simplifies to

$$\chi^2 = \frac{(n_1 - n_2)^2}{n_1 + n_2} \qquad (9)$$

and each pair contributes one degree of freedom.

If we have a large number of such χ^2 values, we may determine whether their frequency distribution agrees satisfactorily with the theoretical distribution. For this purpose it is convenient to set class-limits such that the theoretical probability of each class is equal — say 1/10.

2. Effects of varying volumes.

So far we have assumed the volume of water sampled constant for each haul. Now clearly variation from one station to another will not affect our problem, provided the volume sampled remains the same for both the members of a pair of parallels; but at a single station differences in volume between the parallels will be of importance. Our treatment can be extended to cover this case as follows:

Suppose M and V are defined as before; but set
$P(V)dV$ = probability that V lies between V and $V + dV$.

Let $P_v\ (n)$ = probability that a sample of volume V shall contain n organisms.

Then

$$P(n) = \int_0^\infty P(V)\,P_v(n)\,dV$$

$$P_v(n) = \frac{e^{-MV}(MV)^n}{n!}$$

Write further:

$E(n)$ = mathematical expectation of n

$$\mathop{S}_{n=0}^{\infty} n\ P(n)$$

Then

$$E(n) = \mathop{S}_{n=0}^{\infty} n \int_0^\infty P(V)\,\frac{e^{-MV}(MV)^n}{n!}\,dV$$

$$= \int_0^\infty P(V) \mathop{S}_{n=0}^{\infty} \frac{ne^{-MV}(MV)^n}{n!}\,dV$$

$$= \int_0^\infty P(V)\,MV\,dV$$

$$= M\,E(V)\ . \tag{10}$$

We require further, to obtain the standard deviation of n, the value of $E(n^2)$.

$$E(n^2) = Sn^2P(n)$$

$$= \int_0^\infty P(V)\,Sn^2\,\frac{e^{-MV}(MV)^n}{n!}\,dV$$

$$= M\int P(V)\,VdV + M^2\int P(V)\,V^2dV$$

$$= ME(V) + M^2E(V^2)\ . \tag{11}$$

Now the standard deviations of n and V are given by

$$\sigma_n^2 = E(n^2) - E^2(n)$$

$$\sigma_v^2 = E(V^2) - E^2(V)$$

So that, substituting in (11) and simplifying, we have

$$\sigma_n^2 \qquad ME(V) + M^2\,\sigma_v^2$$

$$\sigma_n^2 = E(n) + E^2(n)\,\frac{\sigma_v^2}{E^2(V)} \tag{12}$$

In practice we do not know $E(n)$ or σ_n, but have to estimate them from the sample values. Now it may be shown that our best estimates of these quantities are given by

$$\bar{n} = \frac{S(n)}{k} \qquad = \text{estimate of } E(n)$$

$$s_n^2 = \frac{S\,(n-\bar{n})^2}{k-1} = \text{estimate of } \sigma_n^2$$

For pairs of samples these become

$$\bar{n} = \frac{n_1 + n_2}{2} \tag{13}$$

$$s_n^2 = \frac{(n_1 - n_2)^2}{2} \tag{14}$$

Writing

$$\chi^2 = \frac{s_n^2}{\bar{n}} = \frac{(n_1 - n_2)^2}{n_1 + n_2}$$

we have, from (12), substituting $\bar{n}$ for $E(n)$,

$$\chi^2 \quad 1 + \bar{n}\,\frac{\sigma_v^2}{E^2(V)} \tag{15}$$

We may therefore expect that the mean value of χ^2 for given values of $\bar{n}$ will be a linear function of $\bar{n}$, having an intercept 1 at $n = 0$ and a slope $\frac{\sigma_v^2}{E^2(V)}$.

We are basically interested in the relative accuracy of our hauls, which is given by

$$\frac{\sigma_n}{E\,(n)} .$$

From (12), (13) and (14) we have

$$\frac{s_n}{\bar{n}} = \sqrt{\frac{1}{\bar{n}} + \frac{\sigma_v^2}{E^2(V)}} \tag{16}$$

which indicates that a limit to our accuracy, regardless of the value of $\bar{n}$, is set by the variation in sample volume.

3. Estimates from fractional counts.

So far we have dealt entirely with total catches. If the total is estimated by counting a fraction p, we may proceed as follows.

Let c be the actual number counted. Then

$$P(c) = S_n \; P(n) P_n(c) \tag{17}$$

were $P_n(c)$ is the probability that our count shall show c organisms if the true total catch is n.

Now

$$P_n(c) = \frac{n!}{c!\,(n-c)!} \, p^c (1-p)^{n-c} \tag{18}$$

And

$$E(c) = S_c \, cP(c) = S_n \left\{ P(n) \; S_c \; cP_n(c) \right\}$$

It may readily be shown that

$$S_c \; cP_n(c) = np$$

and

$$S_c \, c^2 P_n(c) = n^2 p^2 + npq \; .$$

So that we have

$$E(c) = pE(n) = pME(V) \tag{19}$$

Further,

$$\begin{aligned} E(c^2) &= p(1-p)E(n) + p^2E(n^2) \\ &= p^2M^2\sigma_v{}^2 + p^2M^2E^2(V) + pME(V) \\ \sigma_c{}^2 &= E(c^2) - E^2(c) \\ &\quad p^2M^2\sigma_v{}^2 + pME(V) \, . \end{aligned} \tag{20}$$

In this expression for $\sigma_c{}^2$ we may substitute for M our best estimate of it, namely $\frac{c}{pE(V)}$, when we have

$$\sigma_c{}^2 = c + c^2 \frac{\sigma_v{}^2}{E^2(V)} \tag{21}$$

Now write

$$n' = \frac{c}{p}$$

as our estimate of the total catch. Then

$$\sigma_{n'} = \frac{\sigma_c}{p} = \frac{1}{p} \sqrt{c + c^2 \frac{\sigma_v{}^2}{E^2(V)}} \tag{22}$$

And for the coefficient of variation of n' we have

$$100 \, \frac{\sigma_n{}'}{n'} = 100 \sqrt{\frac{1}{c} + \frac{\sigma_v{}^2}{E^2(V)}} \tag{23}$$

$\frac{\sigma_v{}^2}{E^2(V)}$ is the quantity which we have called K^2 in the text.

4. The assumption of random distribution.

Criticism might be directed at our assumption that the distribution of organisms is random. The assumption is admittedly without direct observational support; and no conclusive answer is possible to an argument that non-randomness in the distribution may account for the variations between hauls.

It may, however, be observed that if such non-randomness is an important factor, we should expect to find differences in the variability of different types of organisms. Now the E.-S. data, based entirely on fish eggs, do not differ appreciably from the Künne data, in which fish eggs form only a part of the total. Further, it is possible to analyse the Künne data by types of organism.

In this analysis we have used the equation

$$\chi^2 \qquad 1 + n \; K^2$$

in the following manner. For each type of organism we have summed the values of χ^2 observed, and we have summed the total organisms caught. We have then computed a theoretical value of the summed χ^2 from the equation

$$S(\chi^2) = N + K^2 \, S(\bar{n})$$

when N is the total number of pairs of hauls. Table IV gives the values of $S(\chi^2)$ observed and calculated, using $K^2 = 0.05$.

It will be observed that there are rather large differences between the observed and calculated values. These discrepancies arise, however, very largely from the few hauls giving very large numbers of organisms. If we omit hauls with $\bar{n} > 500$ (of which there are 17) we obtain a considerably closer agreement, as shown in the second part of Table IV. In our opinion this agreement is close enough to justify our use of the assumption of random distribution.

Table IV.

$S(\chi^2)$ by types of organisms.

	Using all pairs				Omitting pairs with $\bar{n} > 500$			
	Number of pairs	$S(\chi^2)$ obs.	$S(\chi^2)$ calc.	Ratio obs: calc.	Number of pairs	$S(\chi^2)$ obs.	$S(\chi^2)$ calc.	Ratio obs: calc.
Small Medusae	89	482.78	905.82	0.53	83	392.40	484.42	0.81
Ctenophores	15	37.06	40.38	0.92	15	37.06	40.38	0.92
Tomopteris	8	38.92	43.25	0.90	8	38.92	43.25	0.90
Calanus	82	387.95	478.50	0.81	77	153.51	280.15	0.55
Decapod Larvae	84	732.15	482.00	1.52	82	415.48	388.05	1.07
Sagitta	52	179.46	402.18	0.45	48	160.18	140.85	1.14
Fish Eggs	41	201.20	207.80	0.97	41	201.20	207.80	0.97
Fish Larvae	37	147.16	85.88	1.72	37	147.16	85.88	1.72

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Contribution No. 117

slow, even under favourable conditions of competition with the parasite.

Symptoms of the wasting disease were present everywhere in June, but there seemed to be no correlation between density of growth and infestation. The wasting is now at its height, so that some beds, as in Great Bay, Long Island, have entirely disappeared.

Specimens from all beds visited were examined microscopically for the *Labyrinthula* described in NATURE last year, and with which confirmatory inoculation experiments have since been performed[1,2]. Without exception it was present and active in streaked or mottled leaves, and in many regions it had already caused considerable wasting.

If previous experience may be taken as an indication, the following seasonal sequence may be expected: Very slow winter growth of the *Zostera* with the *Labyrinthula* passive in the leaves (the spindle form of the parasite has been found in winter specimens), rapid vegetative development in the late spring, with slight increase in activity of the *Labyrinthula*, diminution in the vitality of the plant prior to seed formation in the early summer with sudden activation of the parasite, destruction of leaves, development of new leaf shoots and their subsequent destruction (repeated several times in mid-summer), and final exhaustion of a portion of the stem stock and dying back of part of the bed developed earlier. A number of plants will seed prematurely, or will appear to because more retarded members die off before the normal fruiting period is finished. Barring the development of resistent strains of *Zostera* or general attenuation of the parasite, this seems to be the probable cycle within any progressive return of the plant. This, I realize, is not a cheerful interpretation, but it will be recognized that readjustments no less drastic, but easily overlooked, occur constantly.

I should be grateful to readers of NATURE for particular information on local conditions of the eel-grass in England and on the Continent.

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[1] C. E. Renn, NATURE, **135**, 544 (1935).
[2] C. E. Renn, *Biological Bulletin*, **70**, 148 (1936).

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Persistence of the Eel-Grass Disease and Parasite on the American Atlantic Coast

EARLY in the summer, through facilities extended by Mr. John Lynch, of the U.S. Biological Survey, I was able to make a number of investigations of the existing eel-grass beds along the middle Atlantic coast, in the range of Cape Cod, Massachusetts, to Barnegat Bay, New Jersey. Mr. Lynch also supplied me with systematically taken specimens from beds farther north and south, Casco Bay, Maine, to Chesapeake Bay, Maryland, and with repeated observations from a number of points between. These studies were undertaken to discover to what extent the increasing number of optimistic reports concerning new and larger beds might indicate an effective return of the plant. For the greater part such reports describe late spring growths, during the season of rapid vegetative development, and give no clue of the plant's ability to withstand conditions arising in the less favourable warmer months, when the parasitic *Labyrinthula* is most active, or of its value as winter food for migratory birds, a matter of practical concern.

At the time of the first survey, in early June, small scattered beds of eel-grass, varying in vigour, were found all along the coast so far south as the northern end of Barnegat Bay, and extensive beds of small-leafed growths were described in the eastern shore of Chesapeake Bay, where the latter was being used for packing material. Barnegat Bay and the Delaware coast were notably free from the plant, as were the relatively rocky bays of the Connecticut coast.

The shallow bays of Long Island, Rhode Island, and Massachusetts bore patchy beds often several acres in area, and these were underlaid by extensive mats of healthy stem stock. These beds could conceivably be of ecological value, especially those along Rhode Island and Massachusetts, where the leaves averaged a metre in length, and foliation was relatively dense.

In all beds studied some plants were in seed, and, I understand from Mr. Lynch, a large fraction in the beds south of Cape Cod are now seeding. Seeds have been produced early in the summer for the past three years. It is surprising, therefore, to find but few seedlings even among the scattered plants in what appear to be new beds. Most shoots can be traced back to stem stock one or two seasons old, not very vigorous stock as a rule. If the beds continue to propagate mainly from stem stock, progress will be

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U. S. DEPARTMENT OF COMMERCE
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BUREAU OF FISHERIES
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SUPPLEMENTAL NOTES ON FISHES OF THE GULF OF MAINE

By HENRY B. BIGELOW and WILLIAM C. SCHROEDER

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SUPPLEMENTAL NOTES ON FISHES OF THE GULF OF MAINE[a]

By Henry B. Bigelow and William C. Schroeder, *Woods Hole Oceanographic Institution*

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Introduction

Since the publication by the Bureau of Fisheries of "Fishes of the Gulf of Maine" (Document No. 965, U. S. Bureau of Fisheries, Bigelow and Welsh, 1925) enough new information of general interest has come to hand regarding abundance, distribution, migrations, breeding habits, and food habits to warrant the issuance of a supplement to that publication. Many of these data have been obtained during the investigations carried on by the Bureau; part have been collected from correspondence, while part have been gleaned from published material. Brief notes and records of distribution have been taken from the Bulletin of the Boston Society of Natural History (see Firth (1931), Kendall (1931), MacCoy (1929, 1931a, 1931b, 1933), Schroeder (1931)); from Reports of the Newfoundland Fishery Research Commission (1932–1933); and from the Proceedings and Transactions of the Nova Scotian Institute of Science (Leim 1930). For the distribution of certain New England sharks in South African waters, not referred to in this paper, the reader is referred to Barnard (1925). For allowing us the use of unpublished notes we wish to thank F. E. Firth, Dr. G. W. Jeffers, Dr. A. H. Leim, Walter H. Rich, and O. E. Sette.

The nomenclature used in this supplement is as in "Fishes of the Gulf of Maine."

Hagfish, *Myxine glutinosa* Linnaeus

Recent detailed studies of the sex organs make it certain that the hag is not functionally hermaphroditic as was formerly supposed, but that in each individual either the male portion of the common sex organ matures, with the female organ remaining rudimentary, or vice versa (Conel, 1931). The fact that a 60 cm specimen from Georges Bank contained 30 eggs, 20–25 mm long, shows that large females may produce somewhat more and slightly larger eggs than previously recorded.

Sea lamprey, *Petromyzon marinus* Linnaeus

The known range of the sea lamprey in the western Atlantic has been extended northward to the west coast of Greenland (Jensen, 1926).

Smooth dogfish, *Mustelus mustelus* (Linnaeus)

The genus Mustelus is established for this species by an opinion rendered by the International Commission on Zoological Nomenclature (Smithsonian Institution, 1926, p. 8).

Smooth dogfish are taken so seldom in winter that capture of three by a trawler off Bodie Island, N. C., in 34–45 fathoms, February 1931, is of interest.

Great blue shark, *Prionace glauca* (Linnaeus)

The International Commission on Zoological Nomenclature (Smithsonian Institution, 1925, p. 27) has rejected Valmont's name, Galeus; consequently the correct generic name of the species is Prionace Linnaeus.

The blue shark has recently been recorded from the southwest part of the Grand Bank (Rept., Nfld. Fish. Res. Lab., 1935, p. 79). Although formerly considered a stray in the Gulf of Maine, recent observations have shown the blue shark to be common there in August and September, with occasional records for July. While most often seen offshore, a number were observed and several caught by J. W. Lowes during the summer of 1935 in Massachusetts Bay.

Young ones are seldom seen along our shores, but Robert Goffin reports one only 20 inches long from Menemsha Bight, near Woods Hole, Mass., August 31, 1925; while F. E. Firth records another, 38 inches long, taken 65 miles southeast of Highland Light, Cape Cod, on October 23, 1930.

Dusky shark, *Carcharhinus obscurus* (LeSueur)

The capture of an 11-foot fish on the northeast peak of Georges Bank, August 10, 1931, extends the known range to the offshore banks (Firth, 1931, p. 9).

Shovel-head shark, *Cestracion tiburo* (Linnaeus)

One specimen of this southern species was recorded by Garman (1913, p. 160) from Massachusetts Bay.

This record was omitted from "Fishes of the Gulf of Maine" (Bigelow and Welsh, 1925).

Hammerhead shark, *Cestracion zygaena* (Linnaeus)

Captures of a 12-foot fish, in August 1928, by the swordfishing schooner *Doris M. Hawes*, between Browns and Georges Banks, and of a small one in Halifax Harbor, September 1932 (Vladykov, 1935, p. 8), extend the known range to the northward and eastward.

Thresher, *Alopias vulpinus* (Bonnaterre)

The International Commission on Zoological Nomenclature rejects Valmont's name, *Vulpecula marina*, consequently the next oldest name, *Alopias vulpinus*, must be substituted (Smithsonian Institution, 1925, p. 27).

Mackerel shark, *Isurus nasus* (Bonnaterre)

The fact that *Isurus punctatus* (Storer) is identical with *I. nasus* (Bonnaterre) has been pointed out by Bigelow and Schroeder (1927).

The range of the mackerel shark in the western side of the Atlantic is now known to extend as far north as the Grand Bank of Newfoundland (Rept., Nfld. Fish. Res. Lab., 1935, p. 79).

Sharp-nosed mackerel shark, *Isurus tigris* (Atwood)

The many recent fishery investigations in the Gulf of Maine have indicated that this species is much less common there than *I. nasus*, for whereas many of the latter have been observed and captured since 1923, only one record of the sharp-nosed mackerel shark has come to our attention within that time, a fish 8½ feet long taken 10 miles northeast of Nantucket Lightship, June 22, 1930, by the schooner *Linta* (Firth, 1931, p. 8).

White shark, *Carcharodon carcharias* (Linnaeus)

To the few existing Gulf of Maine records of this ferocious shark are added that of a 13-foot fish taken off Portland in a gill net during October 1931 (identified by Dr. W. C. Kendall); one (identified from a tooth) which attacked a fishing boat off Digby Gut, Bay of Fundy, July 2, 1932;[1] a somewhat doubtful record from off Halifax, June 27, 1930;[2] and another, 15 feet long, apparently of this species, caught off Monomoy Point, Cape Cod, in the fall of 1928.

Spiny dogfish, *Squalus acanthias* Linnaeus

The spiny dogfish is now known along the American coast as far northward as the Straits of Belle Isle. It has also been taken off the west coast of Greenland at Sukkertoppen and in the vicinity of Holsteinborg (Jensen, 1914, p. 7).

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[1] Harry Piers, Proc., Nova Scotian Institute of Science, vol. XVIII, pt. 3, p. 198, 1934.

[2] Ibid., p. 196.

The winter home of the spiny dogfish off the American coast has long been a subject of uncertainty, hence it is of interest to record that the schooner *Victor* found them plentiful about 90 miles southeast of Ambrose Channel Lightship on the tilefish grounds the middle of January 1928, and that the *Albatross II* trawled many specimens in February 1931, between Cape Hatteras, N. C., and Cape Henry, Va., in 16 to 70 fathoms of water. It appears probable, therefore, that the continental slope to the southward of New England is the chief wintering ground of this species on this side of the Atlantic.

Analysis of the sizes and of the stages of development of embryos in females taken at various dates and localities along the coast, and of recent captures of new born dogfish, also adds to our knowledge (previously scanty) of the breeding habits.

Up until 1925 we had no record of new born dogfish within the Gulf of Maine. This, together with the facts that females containing large embryos had been often taken there in early autumn, that dogfish depart entirely from the gulf over the winter, and that new born young had been reported off Long Island in summer suggested that the area of reproduction of this species is confined to waters west and south from Cape Cod.

This is not the case, however, for during the past few years, when special watch has been kept for new born dogfish, we have learned of their presence in considerable numbers on Nantucket Shoals and at various localities in the Gulf of Maine from June to August. Evidently, then, the gulf, as well as the waters off southern New England, is an important nursery. The fact that embryos, sometimes with yolk sac nearly absorbed, have repeatedly been found in females off New York in autumn and on the wintering grounds off Virginia and North Carolina in January and February might suggest that the coastal waters of the Middle Atlantic States also so serve. As no new born "dogs" have yet been reported to the southward of New York at any season, this question remains open, however.

If it should prove that young are born in the southern wintering as well as in the northern summering grounds, the sizes of the embryos, at different localities and dates, would suggest that some are set free as early as January or February; in other words, that the season extends from midwinter right through the spring and summer.

Greenland shark, *Somniosus microcephalus* (Bloch and Schneider)

So seldom is the Greenland shark captured in the Gulf of Maine that it is of interest to record a large one taken off Portland Lightship the summer of 1926, and four others, 4 to 5 feet long, taken in the offing of Portland from 1927 to 1933. A large one was also taken somewhere in the gulf and brought into Gloucester in January 1929, and another, about 15 feet long, caught in an otter trawl on Jeffreys Ledge 27 miles northeast of Thatchers Island, off Cape Ann, February 16, 1931.

KEY TO SKATES AND RAYS

Experience has shown that existing keys are not adequate for the identification of Gulf of Maine skates and rays. The following revision is therefore offered:

1. No long dorsal spine on the tail-- 2
   Tail with long dorsal spines (sting rays)-- 11
2. Two small dorsal fins, but no distinct caudal fin (includes all our common skates)---------- 3
   There is a large triangular caudal fin as well as the two dorsals-------------------- Torpedo
3. Ventral surface with minute rounded tubercles---------------------------- *Raja granulata*,[3]
   Ventral surface smooth--- 4

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[3] Although *Raja granulata* is not known from the Gulf of Maine it can be expected there as it has been recorded from La Have Bank and from the continental edge off Halifax, Nova Scotia, from 200 fathoms.

4. No thorns along mid-zone of disc between eyes and ventrals. Barn-door skate, *Raja stabuliforis*
With one or more rows of thorns along mid-dorsal zone of disc behind eyes 5
5. Posterior third of tail without any large thorns .... Smooth skate, *Raja senta*
Posterior third of tail with one or more rows of large thorns 6
6. Tail with only one row of large thorns .... Young *Raja scabrata*
Tail with three or more rows of thorns 7
7. Mid-row of tail thorns very much larger than any other thorns on tail. Prickly skate, *Raja scabrata*
Mid-row of tail thorns absent or if present not much larger than other thorns on tail 8
8. Three rows of thorns on tail .... Brier skate, *Raja eglanteria*
Four or more rows of thorns on tail 9
9. Length of fish more than 2½ feet .... Big skate, *Raja diaphanes*
Length of fish less than 2½ feet 10
10. Teeth in 70 to 104 rows in each jaw; usually an eye-spot present on each pectoral. Big skate, *Raja diaphanes*
Teeth in 38 to 60 rows in each jaw; eye-spot rarely present .... Little skate, *Raja erinacea*
11. No dorsal fins on tail .... Sting ray, *Dasybatus marinus*
Tail with a dorsal fin in front of spine .... Cow-nosed ray, *Rhinoptera quadriloba*

With regard to the relative abundance of different species of skates on the offshore fishing banks of the Gulf of Maine, it is of interest that on a trip to Georges Bank (chiefly the northeastern part) in September 1929, aboard the otter trawler *Kingfisher*, 37 hauls yielded from 0 to 105 skates per haul (total 495), as follows: *Raja senta*, 57; *R. scabrata*, 325; *R. stabuliforis*, 42; and *R. diaphanes*, 71.

Little skate, *Raja erinacea* Mitchill

This skate has been described as lacking thorns along the midline; but small specimens 3½ to 9½ inches long and one half-grown specimen of 13½ inches, recently examined by us, have this row well developed.

Big skate, *Raja diaphanes* Mitchill

Recent investigations have shown that the range of this skate extends northward not only to the Gulf of St. Lawrence, as long known, but to the Grand Banks as well, and southward to Virginia.

The big skate rarely has a median row of thorns except in the very young, so it is of interest to record a female 18 inches long taken near Jeffreys Ledge, November 1, 1927, which bears a row of large spines along the midline, from the shoulder girdle to the origin of dorsal on the tail.

Young specimens of *R. diaphanes* and *R. erinacea*, especially the females, are not easily separated from each other by a casual glance, hence the number of rows of teeth which they possess has been an important means of identification. Investigators have given various tooth counts ranging from 80 to 110 rows for *diaphanes* and around 50 rows for *erinacea*. Several specimens in the Museum of Comparative Zoology, from New England waters, show 70 to 100 rows of teeth on the jaw of *diaphanes* and from 46 to about 60 rows in *erinacea*.

Prickly skate, *Raja scabrata* Garman

At the time of publication of "Fishes of the Gulf of Maine" the northern boundary of this skate (widespread in the Gulf of St. Lawrence) was unknown in the open Atlantic. Since then it has been found plentifully on the Grand Banks and reported from the east and north coasts of Newfoundland.

Examination of a large number of prickly skates, ranging in size from young, recently hatched, to the largest recorded, allows us to add the following to previous descriptions:

The pavementlike teeth are in 41 or 42 rows in the upper jaw, 40 to 44 rows in lower jaw (4 specimens) and in the male, at least, there are rather sharp cusps on those teeth situated toward the angles of the jaw. The number of large curved thorns along the midline of the tail and body was as follows on 23 specimens: 12 (2), 13 (10), 14 (8), 15 (3), with no correlation between the number of thorns and the size of the specimen. The brownish back is usually marked with small white spots. The young are more spotted than the adults and have six or seven dark cross bars on the upper surface of the tail.

This skate grows to 3 feet in length, or slightly larger; a 32-inch fish is about 23 inches wide. The smallest nearly mature male found was 26 inches long.

Since nothing was known of the breeding habits of the prickly skate, it is worth recording that a specimen 32 inches long taken on the northern part of Georges Bank, September 22, 1929, had one egg capsule measuring 3 by 2¼ inches (exclusive of tendrils) in each oviduct, and that a male, 35¼ inches long had nearly ripe milt, but a number of other large females taken at the same time were barren.

Prickly skates caught on Georges Bank in September 1929, had been feeding on fish, shrimps, spider crabs, anemones, and worms; this is the first definite information as to the diet of this skate.

Brier skate, *Raja eglanteria* Bosc

An unusually large one, 37¼ inches long, was taken off Woods Hole, Mass., in August 1932.

Additional to the few Gulf of Maine records of this skate already reported are two specimens taken on Nantucket Shoals, near Round Shoal Buoy, by the *Halcyon*, one in July, the other in September 1924. This is a shoal water species, the deepest capture made by *Albatross II* between southern New England and the offing of Chesapeake Bay being in 38 fathoms.

Smooth skate, *Raja senta* Garman

The smooth skate, formerly believed rare in the Gulf of Maine, is now known to be quite generally distributed on our offshore fishing banks, as well as on soft bottom in the deeper parts of the gulf. We have taken it commonly on Georges Bank, in South Channel, in the deep water (80–100 fathoms) just off Cashes Ledge, near Jeffreys Ledge, and off Chatham. The shoalest capture was from 25 fathoms.

The largest specimen obtained was 24 inches long.

Barn-door skate, *Raja stabuliforis* Garman

Young specimens are seldom reported, hence it is of interest to record one of 7½ inches taken on the western edge of Nantucket Shoals July 14, 1930, in 28 fathoms. This fish had essentially the same characters as the adult. The range of the barn door skate is now known to extend northward to the western part of the Grand Bank of Newfoundland.

Torpedo, *Narcacion nobilianus* (Bonaparte)

As no torpedoes had been reported to the eastward of Cape Cod since 1896, the captures of a 52-inch specimen weighing 78 pounds, on the southwest part of

Georges Bank, December 8, 1930, and of another of 39 inches at Provincetown, July 28, 1931, deserve mention here.

Chimaera, *Chimaera affinis* Capello

It was formerly believed that the chimaera did not exceed a length of about 3 feet, but a specimen measuring 49 inches in length, 17½ pounds in weight dressed, was taken October 15, 1930, 85 miles south by west of Cape Sable in a depth of about 400 fathoms (Firth, 1931, p. 9).

Common sturgeon, *Acipenser sturio* Linnaeus

Although sturgeon have seldom been reported from offshore, the recent captures of a 268-pound fish in South Channel the end of April 1928, of another of 420 pounds in April 1929, of a 335-pound fish trawled on Browns Bank in April 1936, and of a 435-pound fish on Georges Bank, latitude 41°00′ N., longitude 67°45′ W., on January 7, 1931, indicate that they are to be occasionally found on our outer fishing banks.

Short-nosed sturgeon, *Acipenser brevirostris* LeSueur

A 30-inch specimen, taken at Provincetown about 1907, now in the collection of the Museum of Comparative Zoology, is the only reliable record for the Gulf of Maine. This record was omitted from "Fishes of the Gulf of Maine" (Bigelow and Welsh, 1925).

Eel, *Anguilla rostrata* (LeSueur)

The known range of the American eel in northern waters has been extended to the west coast of Greenland (Jensen, 1926, p. 101).

American conger, *Conger oceanica* (Mitchill)

The American conger, long considered identical with the European, has recently been shown by Schmidt (1931) to be a distinct species, characterized by having fewer (140–149) vertebrae than the European (154–163 vertebrae); a relationship paralleling that between the American and European eels of the genus *Anguilla*.

The American conger ranges along the continental shelf northward to Cape Cod. Its southern boundary cannot be stated until the congers of the coasts of North and South America have been critically compared.

Additional to the few records of larvae already reported from the Gulf of Maine are those of two specimens (4¼ inches long) picked up on the beach at Newburyport, Mass., in November 1929, which were sent to us for identification.

Dr. Johannes Schmidt's discovery [4] of very young larvae in the West Indian region, but nowhere else, points to this as the chief, if not the only, spawning ground of the American conger.

Snake eel, *Pisodonophis cruentifer* Goode and Bean

Goode and Bean's (1896, p. 147) record of this species from Jeffreys Bank—the only one for the gulf—was omitted from "Fishes of the Gulf of Maine." A number of specimens have been taken recently between the offings of Nantucket and of Cape Henry, Va., in depths ranging from 24 to 245 fathoms by the *Fish Hawk* and the *Albatross II*.

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[4] See Schmidt, 1931, p. 602, for a discussion of this question.

Herring, *Clupea harengus* Linnaeus

The northern limit to the known range of the herring in the Western Atlantic has been extended to the west coast of Greenland by Jensen (1926, p. 101).

Herring are so seldom taken in any large numbers on the offshore banks that it is of interest to record a catch of 2,800 pounds in South Channel and 3,000 pounds on the northern edge of Georges Bank, in October 1931.

Mass destruction of young herring, cast up on the beaches has occurred from time to time in various harbors in the Gulf of Maine. A recent occurrence of this sort was reported by Dr. Austin H. Clark, who, in Manchester Harbor on the north side of Massachusetts Bay, early in August 1925, observed that the mud flats were white with stranded herring which measured 3 to 5 inches in length. Another such destruction took place in the same harbor in the summer of 1928.

Alewife, *Pomolobus pseudoharengus* (Wilson)

So little is known about the habits or migrations of the alewife while at sea that it is of interest to record the capture by *Albatross II* of 18 adults, 10 to 11 inches long, by otter trawl, seventy odd miles off Barnegat, N. J., on March 5, 1931.

Blueback, *Pomolobus aestivalis* (Mitchill)

The maximum length of this herring is usually given as about 1 foot but we have seen examples of it ranging up to 15 inches.

The capture of seven adult specimens by *Albatross II*, on March 5, 1931, about 70 miles off Barnegat, N. J., suggests that, like its relative the sea herring, the blueback moves out from land, and passes the cold season near the bottom, thus throwing some light on the probable winter home of the Gulf of Maine stock.

Thread herring, *Opisthonema oglinum* (LeSueur)

The capture of a single specimen, 7 inches long, off Monomoy Point at the southern angle of Cape Cod in August 1931, extends the known range of this southern herring to the Gulf of Maine. Occasionally the thread herring is taken off southern New England; it was even reported as rather common in Buzzards Bay and Vineyard Sound in the summer of 1885. As it is essentially a tropical fish it is not apt, however, to reach the gulf except as the rarest of strays.

Round herring, *Etrumeus sadina* (Mitchill)

This herring, recorded by Bigelow and Welsh (1925, p. 91) as *Etrumeus teres* DeKay, appears very rarely to stray past Cape Cod. Hence, it is of interest to record the capture of one specimen in Yarmouth River which empties into Casco Bay, and one in the bay itself, on September 15, 1924.

Anchovy, *Anchoviella mitchilli* (Cuvier and Valenciennes)

This species is listed by Bigelow and Welsh (1925, p. 124) as *Anchovia mitchilli.* The subgenus Anchoviella Fowler differs from the subgenus Anchovia Jordan and Evermann chiefly by having much fewer gillrakers, the former having about 35 to 50 and the latter 100 or more.

Striped anchovy, *Anchoviella epsetus* (Bonnaterre)

A record from off the Presumpscot River, near Portland, October 8, 1930 (Kendall 1931, p. 11) is the first for the Gulf of Maine. This anchovy is now known from as far northward as Halifax harbor where a number were seined September 29, 1931 (Vladykov 1935, p. 3).

Argentine, *Argentina silus* Ascanius

Until recently the argentine was considered rare in our waters, for only odd examples had been brought in from widely scattered localities. The development of otter trawling proved that argentines are in reality fairly common around the edge of Georges Bank and off Cape Cod in deep water. Thus, along the northern and northwestern slopes of the bank and to the eastward of Cape Cod, in depths of 80 to 100 fathoms, it is not unusual for a haul of the trawl to bring in from one to a dozen, and as much as 15,000 pounds has been reported by one boat during a week's fishing (Firth 1931, p. 11). It also occurs in the deep central basin of the gulf, for the *Albatross II* has recently (July 1931) trawled a specimen in 115 fathoms off Mount Desert Rock.

Pearlsides, *Maurolicus pennanti* (Walbaum)

Additional Gulf of Maine records of this species include one specimen 41 mm long taken from the stomach of a cod, on Platts Bank, July 27, 1924; one 43 mm long, also from a cod's stomach, on Cashes Ledge, August 16, 1928; and four, 32 to 39 mm long, from the stomachs of two pollock, caught in 20 fathoms, 7 miles southeast of Bakers Island, Mount Desert, Maine, July 24, 1930.

Viperfish, *Chauliodus sloanei* Bloch and Schneider

A specimen found in the stomach of a swordfish caught in the gully between Browns and Georges Banks in 1931 is the second to be definitely recorded from within the Gulf of Maine.

Lancetfish, *Alepisaurus ferox* Lowe

A record of a 5½-foot specimen of this rare fish caught alive in the surf on Block Island, R. I., March 12, 1928, is of especial interest even though outside the limits of the Gulf of Maine. An excellent photograph, sent in by Mrs. Elizabeth Dickens, shows the upper lobe of the caudal prolonged as a long filament, which most of the specimens so far seen have lost. This specimen had been feeding on small dogfish.

Needlefish, *Scomberesox saurus* (Walbaum)

A specimen gaffed at the surface from the *Albatross II* on northern Georges Bank, September 20, 1928, is the only definite offshore record for the Gulf of Maine although the needlefish has been taken in various localities there alongshore.

Trumpetfish, *Fistularia tabacaria* Linnaeus

Recent reports of the trumpetfish at Port Mouton, Nova Scotia, and on the south coast of Newfoundland, show that this tropical species may stray much farther north than previously supposed.

Pelagic pipefish, *Syngnathus pelagicus* Linnaeus

A single specimen 3½ inches long, taken on Georges Bank (lat. 42°09′ N., long. 66°41′ W.) September 20, 1927, by the *Albatross II*, is the only Gulf of Maine record. This specimen was dipped up with a mass of gulf weed (Sargassum) and was the only one found in a large amount of weed that was examined.

Common pipefish, *Syngnathus fuscus* Storer

Pipefish are rarely taken on bottom far from the immediate shore waters, hence it is of interest to report the capture of four specimens 4½ to 6 inches long at a depth of 19 fathoms 10 miles south of No Mans Land, February 5, 1930.

Northern barracuda, *Sphyraena borealis* DeKay

A specimen about 2 inches long found alive in the surf at Nauset Beach, Cape Cod, September 26, 1930, by Dr. Edward P. Richardson, is the only record thus far reported for the Gulf of Maine. Young fry, a few inches long, are taken, however, from time to time in the region of Vineyard Sound and Buzzards Bay on the southern coast of New England, from July to December.

Mackerel, *Scomber scombrus* Linnaeus

The body length of the mackerel is erroneously given as about three and one-half times the depth by Bigelow and Welsh (1925, p. 188); actually, it is four to five and one-half times the depth.

A small mackerel taken at Cape Lookout, N. C., in February 1925 (Coles, 1926, p. 105), extends the known range southward beyond Cape Hatteras.

Recent captures of a mackerel weighing 7½ pounds,[5] and of another of 7¼ pounds, 26 inches long, both of which we, ourselves, examined, shows that occasional giants occur, for the weight seldom exceeds 4 pounds or the length 22 inches.

Tuna, *Thunnus thynnus* (Linnaeus)

Larger catches of tuna have been made within the Gulf of Maine in recent years partly, at least, because of an increased market demand for the fish. Thus, compared with the 69,868 pounds recorded for Massachusetts and Maine in 1919, the catch of 1934 amounted to 356,904 pounds, of which 254,076 pounds came from Cape Cod. The Nova Scotian shore of the Gulf of Maine yielded about 24,000 pounds in 1924 and 10,000 pounds in 1929. At present the annual catch for the gulf is probably between 300,000 and 400,000 pounds. Assuming an average weight of 300 pounds (probably too little, for the average weight of about 90 tuna caught off the coast of Maine in 1926 was about 540 pounds), this would represent a thousand or more fish. Off the outer coast of Nova Scotia, where tuna have been taken in larger numbers than within the Gulf of Maine, the annual catches from 1917 to 1933 have fluctuated between 152,000 and 1,550,000 pounds.

The heaviest New England fish on record, taken off Rhode Island about 1913, weighed 1,225 pounds, while four or five fish have been brought into Boston that weighed approximately 1,200 pounds. Another fish weighing 1,300 pounds was shipped in 1924 from Nova Scotia to Boston (Sella, 1931, p. 61).

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[5] Atlantic Fisherman, August 1925.

Small and moderate sized tuna (below 100 pounds) are comparatively rare in the Gulf of Maine. However, schools composed of individuals estimated to weigh not more than 40 to 70 pounds were observed around Boston lightship July 13 and 14, 1935.[6] None below 20 pounds has been recorded within the gulf, but off southern New England, especially near Block Island, small tuna are sometimes caught, there being an unusual run of them (8 to 12 pounds) in 1928. Thus it is probable either that the lower temperatures of the Gulf of Maine are a barrier to the smaller-sized tuna, or that they find less favorable feeding grounds there than do the larger sizes.

Off the New England coast the first schools are sighted late in June or early July to the southward of Block Island, over depths of about 85 fathoms, and a few days later they appear inshore. At first the fish are hungry, and there is some reason to believe that their summer migrations follow their breeding period. An example of their seasonal abundance in the shore waters of the coast of Maine may be had from the catches made in the vicinity of Casco Bay in 1926, where about 70 fish were taken in July, 17 in August, 3 in September, and 1 on October 4.

Common bonito, *Sarda sarda* (Bloch)

Two fish were reported from the mouth of Kennebec River in July and one in September 1930, and one from southern Nova Scotia (Vladykov, 1935, p. 7) in the latter month.

In looking through the records of the catches made by a certain set of pound nets at Provincetown over a period of 10 years, we find the earliest catch for that locality was in July (1915), and the latest on October 4 (1919).

Spearfish, marlin, *Makaira albida* (Poey)[7]

No spearfish were reported in the Gulf of Maine from about 1880 until 1925. Since then, however, seven specimens have been brought in, all in summer, one of them from off Portland, the others from Georges, Browns, and Sable Island Banks, the last being the most northerly record for the species in the western North Atlantic. These specimens ranged from 5 feet to nearly 16 feet in length and from 21 to about 700 pounds in weight.

Additional descriptive data based on two New England specimens examined by us are as follows: The first dorsal fin of one specimen has 47 stiff rays, the other fish having 48. This fin is separated from the second dorsal by a space equal to the length of the latter in the one fish, by a shorter space in the other. The first anal fin (2 spines and about 12 or 13 rays), situated below the rear part of the first dorsal, is triangular, its first rays forming a sharp angle.

Swordfish, *Xiphias gladius* Linnaeus

The largest swordfish definitely recorded from the Gulf of Maine was one, caught in the summer of 1921 by Capt. Irving King and landed at the Boston Fish Pier, that weighed 915 pounds dressed—hence, upward of 1,000 pounds alive (Fishing Gazette, September 1921, p. 13). The specimen was not measured, but the sword being more than 5 feet, the total length of the fish must have approximated 15 feet.

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[6] Data furnished by J. W. Lowes.

[7] Recorded by Bigelow and Welsh (1925, p. 227) as *Tetrapturus imperator* (Bloch and Schneider).

In 1931, another large fish was caught, 644 pounds in weight, dressed, 13 feet in length, with a sword measuring 3 feet 8 inches.

Young swordfish are so rarely reported off the New England coast that it is of interest to record the capture of a 2-foot fish, weighing 7¾ pounds, taken by the *Dacia* on a trawl line September 2, 1931, on Georges Bank.

Pilotfish, *Naucrates ductor* (Linnaeus)

Up to 1925 only three definite records for the Gulf of Maine had come to hand. Since then we have learned of the capture of six more pilotfish, off Portland, in Provincetown Harbor, to the southeast of Cape Cod, and on the northern edge of Georges Bank, during the summer and fall months in the years 1921, 1924, 1929, 1931, and 1933. Vladykov (1935, p. 6) reports two specimens from Sable Island Bank and one from Sambro, off Nova Scotia, in the period 1932–34.

Rudderfish, *Seriola zonata* (Mitchill)

The known range of the rudderfish has been extended northward to Halifax, Nova Scotia (Leim, 1930, p. xlvi, as *S. dumerili*).

One fish was caught on a smelt hook off a Portland wharf in September 1921; a 5½-inch fish was taken off Boston in September 1929; another, 17½ inches long, from South Channel the same month; and a 6-inch specimen on Nantucket Shoals in August 1930.

Mackerel scad, *Decapterus macarellus* (Cuvier and Valenciennes)

One specimen, 7 inches long, was taken in a trap at Richmond Island, off Cape Elizabeth, in September 1931, this being only the second recorded for the Gulf of Maine.

Saurel, *Trachurus trachurus* (Linnaeus)

One specimen of this fish, rare to the northward of Woods Hole, Mass., was taken in Casco Bay on August 12 and another near Castine Bay, Maine, on October 15, 1930 (Kendall, 1931, p. 11).

Big-eyed scad, *Trachurops crumenopthalma* (Bloch)

Two specimens, recently taken off Cape Cod, one at Provincetown, the other about 8 miles off the beach at Chatham, are the only positive records of this species for the Gulf of Maine. As it is caught from time to time, however, in the summer and fall as far northward as Woods Hole, it may be expected to round the cape occasionally. This scad has been recorded from Canso, Nova Scotia by Cornish (1907, p. 85).

Hardtail, *Caranx hippos* (Linnaeus)

A hardtail taken off Provincetown in 1933 is the second reported from the Gulf of Maine. Several specimens about 2 inches long were taken the summer of 1933 in Musquodoboit Harbor, Nova Scotia (Vladykov, 1935, p. 4).

Hardtail, *Caranx crysos* (Mitchill)

One fish was taken off Chatham in 1933.

Lookdown, *Selene vomer* (Linnaeus)

During the autumn of 1933 many small lookdowns were reported from traps at the mouth of Casco Bay, one also from Beverly Farms, and another from North Truro, an unusual incursion, for only three specimens had previously been recorded in the Gulf of Maine. Jones (1882 p. 89) and Honeyman (1886 p. 328) record this species (young) as occasional in the shore waters of Nova Scotia, presumably along the east coast.

Leatherjacket, *Oligoplites saurus* (Bloch and Schneider)

A specimen taken in a trap off the outer beach at Chatham is the only record for the Gulf of Maine.

Bluefish, *Pomatomus saltatrix* (Linnaeus)

For many years no bluefish had been reported north of Cape Ann, until 1925, when one was caught off Halifax, Nova Scotia. This seems to have presaged a temporary extension of range, for numbers of them visited the inner coasts of the gulf northward to Casco Bay in the summer of 1927, while in 1930 the bluefish was again reported at Halifax (two specimens) and at Port Mouton, Nova Scotia (one specimen, Leim, 1930, p. xlvi).

Common dolphin, *Coryphaena hippurus* Linnaeus

A dolphin about 3½ feet long taken 60 miles south-southwest of Cape Sable, in the deep gully between Browns and Georges Banks by the trawler *Natalie Hammond*, August 15, 1930, is the first Gulf of Maine record. The specimen is now in the collection of the Boston Society of Natural History.

Opah, *Lampris regius* (Bonnaterre) [8]

A specimen about 3 feet long was taken in July 1925, on Western Bank, southwest of Sable Island, by the schooner *Falmouth* (Radcliffe, 1926), while another of about the same size stranded on the beach at Hyannis, Mass., on September 17, 1928.

Johnson's sea bream, *Taractes princeps* Johnson

A fish taken on Browns Bank, off Cape Sable in January 1928 is the first record of this species for the western Atlantic. This bream previously was known only from Madeira, in the eastern Atlantic. For a detailed account and comparison with allied species see Bigelow and Schroeder (1929).

Butterfish, *Poronotus triacanthus* (Peck)

Recent records show that the northward range of this species extends to the east coast of Newfoundland, as well as to Nova Scotia as has long been known.

It now seems well established that the butterfish actually withdraw from the gulf when they disappear in the autumn, as they do from the immediate shore waters farther south, and from inland waters such as Chesapeake Bay. Until very recently the winter home of the butterfish was unknown; but as they are now often taken in the winter otter trawl fishery recently established off the coast between Chesapeake

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[8] This species was given as *Lampris luna* (Gmelin) by Bigelow and Welsh (1925, p. 242).

Bay and Cape Hatteras, it appears that they move out to sea to winter on the outer part of the continental shelf as do several other common Gulf of Maine fishes.

The illustrations of larvae 2.1 and 3.4 mm long credited by Kuntz and Radcliffe (1918) to the butterfish and reproduced by Bigelow and Welsh (1925, fig. 116, *c* and *d*) have since been proved to belong to one of the hakes.

Harvestfish, *Peprilus alepidotus* (Linnaeus)

Five or six specimens were reported caught in floating traps at Richmond Island, off Cape Elizabeth, Maine, in July 1929, while another was taken at the mouth of the Damariscotta River, Maine, in August 1933, the most northerly record for the species.

Striped bass, *Roccus lineatus* (Bloch)

The striped bass considerably increased in abundance along both shores of Cape Cod between 1928 and 1932, then decreased again as illustrated by the following catches reported for Barnstable County, Mass.: 1928, 8,060 pounds; 1929, 18,665 pounds; 1930, 27,385 pounds; 1931, 33,600 pounds; 1932, 30,926 pounds; 1933, 4,500 pounds. Anglers as well as commercial fishermen have also caught some numbers along the Eastham-Chatham Beaches and marshes during the past few years, while a 44¾ pound bass was caught near Brant Rock on the southern shore of Massachusetts Bay, in November 1930. A small stock seems also to have built up in the brackish tributaries of Plum Island Sound north of Cape Ann, for some were taken in Parker River by anglers during the few years previous to 1930, while in that year (when fishing restrictions were relaxed) 8,700 pounds were reported thence, though smaller numbers since then. But this increase did not extend northward beyond Massachusetts waters, for the commercial reports from the States of New Hampshire and Maine did not mention bass at all in 1924, or in 1928–33.[9]

Striped bass so rarely stray away from the immediate shoreline that it is of interest to mention the capture of a 6-pound fish in a gill net on Cod Ledge, 3 or 4 miles off Cape Elizabeth, Maine, October 15, 1931.

Sea bass, *Centropristes striatus* (Linnaeus)

Sea bass are seldom taken within the Gulf of Maine, and even on the southern New England coast are rarely caught later than early November, hence the reported capture of a 5-pound fish in December 1930, 5 miles east of Pollock Rip Lightship, in 24 fathoms, is noteworthy.

Triggerfish, *Balistes carolinensis* Gmelin

Previous to 1925, only one specimen of the trigger fish had been reported from the Gulf of Maine. Actually, this species must drift over the offshore rim of the gulf more often than the paucity of early records would suggest, for a specimen was recorded from Casco Bay in August 1931; another was taken in 1932 near Plymouth; a third, 15 inches long, was gaffed at the surface, on the southeast part of Georges Bank, from the fishing vessel *Huntington Sanford*, in July 1929; and two small fry, 2 to 3 inches in length, were picked up on the northeast part of the bank in mid-September 1927, by the *Albatross II*. The fact that these last were taken with gulf weed (Sargassum) suggests that triggerfish are most apt to appear on the banks with the latter.

Filefish, *Monacanthus hispidus* (Linnaeus)

The filefish appears in the inner parts of the gulf only as a stray from warmer seas, recent records being that of a fish taken off Seguin, September 12, 1929, one off Portland lightship, July 17, 1931, and a 6-inch fish at Provincetown, November 6, 1929. On the offshore banks, however, it is to be expected more frequently (which accords with its southern origin) for the *Albatross II* gathered 181 small fry 1 to 2 inches long, on the northeastern part of Georges Bank among floating gulf weed (Sargassum) in September 1927; while a larger one was picked up to the southeast of Cape Cod in that same month of 1930.

Filefish, *Monacanthus ciliatus* (Mitchill)

A 7-inch fish taken in a Provincetown trap in November 1929 is the second (and only recent) record of this species within the Gulf of Maine (Firth, 1931, p. 13). A straggler has been reported, however, from Newfoundland—far to the north of its previously known range.

Unicornfish, *Alutera scripta* (Osbeck)

Two specimens of this fish, 5 and 5½ inches long, respectively, caught on the western edge of Georges Bank, constitute the first Gulf of Maine record (Mac Coy, 1931a, p. 16).

Puffer, *Spheroides maculatus* (Bloch and Schneider)

A specimen taken off Long Island, Portland Harbor, on July 24, 1933, is the first to be recorded from the northern boundary (Casco Bay) of this species since 1896.

Rosefish, *Sebastes marinus* (Linnaeus)

It is now known that rosefish may be born in the Gulf of Maine as early as the end of April, for in 1930 we saw gravid females during the last half of that month. In July 1931 the *Albatross II* trawled many gravid females, 10 to 13½ inches long, in the central basin of the gulf; one of these, 13 inches long, contained approximately 20,500 young 6 to 7 mm long, ready to be spawned.

The fact that we obtained many young fish 2½ to 5¾ inches in length, off the coast of Maine from April to August, suggests that this is the approximate size attained during their first year of life.

Recent catches of 75–625 rosefish per haul in a trawl by the *Atlantis* in 70–130 fathoms in the western and northeastern parts of the gulf are evidence of the abundance of this species over the soft bottoms of the basins, as well as in other parts of the gulf. The commercial importance of this species has greatly increased of late, the reported landings having risen from 1,288,000 pounds in 1934 to 14,100,000 pounds in 1935.

Black-bellied rosefish, *Helicolenus dactylopterus* (De la Roche)

A fish 13 inches long, trawled on the eastern edge of Georges Bank in 150 fathoms, October 6, 1929 (Firth, 1931, p. 13), is the first record for this species within the Gulf of Maine. In addition to previous records from outside the gulf, a number of small fish (1¼ to 3½ inches) were trawled off southern New England in 80 to 118 fathoms during 1930.

Hook-eared sculpin, *Artediellus uncinatus* (Reinhardt) [10]

This sculpin is now known to be generally distributed in the Gulf of Maine in depths greater than 20 to 30 fathoms. Thus, in addition to the Massachusetts Bay records of many years ago, we have recently taken it repeatedly near Mount Desert, off Cape Elizabeth, near Jeffrey's Ledge, around Cashes Ledge, along the northern slopes of Georges Bank, in the southeastern part of the basin of the gulf, and at the entrance to the deep gully between Georges and Browns Banks, in depths ranging from 20 to 150 fathoms. Individual hauls have yielded up to six or eight specimens, both on hard and on soft bottom.

After examining specimens from New England waters and comparing published drawings of European fish, we can find no major differences between the hook-eared sculpins of the eastern and western Atlantic.[11]

Mailed sculpin, *Triglops ommatistius* Gilbert

This sculpin is not as rare in the Gulf of Maine as was formerly supposed, for during the past few years we have trawled specimens near Mount Desert, in Massachusetts Bay, off Cape Ann, off Cape Cod, and around the northern slope of Georges Bank, in depths of 20 to 140 fathoms, in various months from spring to autumn. The most southerly locality was about 10 miles east of Chatham.

Longhorn sculpin, *Myoxocephalus octodecimspinosus* (Mitchill)

Numerous young specimens 1½ to 2 inches long taken in September, and 3 to 3½ inches in February, suggest that the longhorn sculpin is about 2 to 3 inches long at 1 year of age, spawning as it does in late fall.

Deep-sea sculpin, *Cottunculus microps* Collett

A specimen, about 2 inches long, trawled by the *Albatross II* on the northern slope of Georges Bank, in a depth of 120 fathoms, on July 24, 1931, is the third record for the Gulf of Maine proper.

Sea raven, *Hemitripterus americanus* (Gmelin)

The fact that fish of both sexes with gonads only partially developed have recently been found on Nantucket Shoals late in June, added to previous captures of ripe females off southern New England in November and December shows this to be a late fall and early winter spawner. The sea raven is a prolific fish, for a female 20 inches long that we caught off Boothbay Harbor, Maine, in April 1925, contained about 10,000 eggs. The fact that these were definitely of two sizes, the smaller averaging 1.5 mm in diameter, the larger about 3 mm, raises the interesting question whether individual sea ravens may spawn more than once during the year.

The sizes of the few young sea ravens that have been taken in the Gulf of Maine suggest that they reach a length of 2 to 4 inches by the middle of the first summer, when 6 to 8 months old; and about 6 inches by the following April, at an age of 1½ years.

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[10] Given as *Artediellus atlanticus* Jordan and Evermann by Bigelow and Welsh (1925, p. 314).

[11] Jordan, Evermann, and Clark (1930, p. 377) in the Check List of Fishes placed *Artediellus atlanticus* Jordan and Evermann in the synonymy of *A. uncinatus* Reinhardt.

Sea snail, *Neoliparis atlanticus* Jordan and Evermann

The sea snail, previously unknown offshore, has recently been taken on Georges and on Browns Banks. Its range has recently been found to extend as far southward as the offing of Atlantic City, N. J. (Lat. 39°20′N.). Most of the specimens were found living in scallop shells (*Pecten magellanicus*), as is so often the case.

Striped sea snail, *Liparis liparis* (Linnaeus)

This sea snail was formerly known as far southward as New York but the *Albatross II* has taken it off Delaware Bay and the *Grampus* off Assateague, Va. (Welsh, 1915, p. 2).

Red-winged sea robin, *Prionotus strigatus* (Cuvier)

A specimen was taken off Monhegan, Maine, in 40 fathoms, in an otter trawl November 19, 1933. This is the most northerly record for this straggler in the Gulf of Maine.

Remora, *Remora remora* (Linnaeus)

Recent Gulf of Maine records of this species include one found on the bottom of a lobster trap in Portland Harbor in 1931, probably brought in by a schooner from the West Indies; one found sucking to the gills of a blue shark (*Prionace glauca*) that was caught on the northeast edge of Georges Bank, August 1, 1931; one in Cape Cod Bay in September 1934, and one off Provincetown in August 1935, taken by C. W. Lowes on blue sharks; also two specimens, 6 and 17 inches long, respectively, taken on August 3, 1932, 220 miles east-southeast of Cape Ann. Previously it had been recorded only once from the Gulf of Maine.

Rock eel, *Pholis gunnellus* (Linnaeus)

Recent records show that the rock eel occurs in considerable numbers on the offshore banks in the Gulf of Maine down to at least 40 fathoms and occasionally even to 100 fathoms (Schroeder, 1933, p. 5) as well as inshore. So many have been found in the stomachs of cod and pollock caught on Nantucket Shoals, Georges Bank, Browns Bank, Cashes Ledge, etc., that it must be an important food of these two species.

The range of the rock eel recently has been found to extend south to the latitude of Delaware Bay, where in February 1930 *Albatross II* trawled two specimens in 23 and 38 fathoms, respectively.

Snake blenny, *Lumpenus lampetraeformis* (Walbaum)

Recent captures, by *Albatross II*, of adult snake blennies (one specimen each) off Mount Desert, off Boone Island, and on Stellwagen Bank, in depths ranging from 28 to 88 fathoms, added to earlier records from Massachusetts Bay and from the Bay of Fundy region, show that this species is generally distributed over the gulf, as records of its larvae had suggested. So slender and active is this fish that it can easily escape through the meshes of any of the nets used by commercial fishermen, hence it is seldom reported.

Color notes taken from a 12-inch specimen are as follows: The body had brown markings on a whitish ground, the head being pale brown. The dorsal fin was marked obliquely with 18 pale bars, the caudal transversely with 8. The anal rays were pale brown against a colorless membrane, the ventrals white, while the pectorals were tinged with brown.

One of 19 inches caught on the eastern slope of Stellwagen Bank in 42 fathoms in July 1931 is the largest on record.

Shanny, *Leptoclinus maculatus* (Fries)

One specimen of this stray from the north was trawled on the northeast part of Georges Bank in August 1926 and four (4 to 4½ inches long) were taken off Chatham, Cape Cod, in 28 fathoms, May 1, 1930, by the *Albatross II*. This is the most southerly record for the species.

Arctic shanny, *Stichaeus punctatus* (Fabricius)

A specimen 4½ inches long of this arctic species, taken one-half mile off Little Duck Island near Mount Desert, Maine, from the stomach of a cod, on April 30, 1930, is the first record for the Gulf of Maine; the only record indeed to the southward of Newfoundland. This specimen was in such good condition that it unquestionably had been living in the immediate vicinity.

Radiated shanny, *Ulvaria subbifurcata* (Storer)

This shanny was previously known to be rather common in the northeastern part of the gulf, and enough have now been found in the stomachs of cod caught on Cashes Ledge, Georges Bank, Nantucket Shoals, and other offshore grounds to show that it is widespread in other parts of the gulf as well, on hard bottom. The deepest capture was in 45 fathoms.

Wrymouth, *Cryptacanthodes maculatus* Storer

Recent captures of two specimens in the central basin of the Gulf of Maine, July 1931, in 88–95 fathoms, of three in August 1936, in 72–100 fathoms, and of another on the continental slope between 245 and 325 fathoms, shows that this species is not as closely restricted to the vicinity of the coast as previously supposed and that it reaches considerably greater depths.

The locality of the capture (taken by *Atlantis*) last mentioned (lat. 39°31′ N; long. 72°16′ W.) also extends the known range somewhat farther south.

Spotted wolffish, *Anarrhichas minor* Olafsen

This Arctic species is seldom taken within the Gulf of Maine, hence the capture of a small specimen, weighing 3¼ pounds, on a trawl, off Portand Lightship on April 23, 1927, is worthy of mention. On the Scotian banks, however, it is not so uncommon, for we have records of 2, 37 and 54 inches long, respectively, caught on Sable Island Bank in January 1934 and 5 more in March of that year. Usually about 5 to 10 from this general region are landed each year at the Boston Fish Pier.

Eelpout, *Zoarces anguillaris* (Peck)

Many small specimens from 1.8 inches long upward, have recently been collected along our coast between Maine and New Jersey, including (within the gulf) Mount Desert, Stellwagen Bank, Georges Bank, and the vicinity of Chatham, suggesting that the eelpout breeds successfully throughout this range. And as all the young thus far taken have been caught in depths of 20 to 45 fathoms, probably this is the usual spawning zone. Although eelpouts have seldom been reported deeper than 50 fathoms, *Albatross II* recently (July 1931) trawled a number in the basin of the gulf as deep as 90 fathoms.

The sizes, in different months, of the young fry show that eelpouts in the Gulf of Maine grow to a length of about 2 inches in the first 6 months of their lives, and 3 inches in 9 months, agreeing in this respect with the growth-schedule of Bay of Fundy eelpouts derived by Clemens and Clemens (1921, p. 74) from the annual rings on the otoliths. Small specimens 5 to 6½ inches long taken from February to May are probably about 1½ years old.

Young eelpouts, up to 3 or 4 inches long, are checkered along the sides, and irregularly blotched on the back with light and dark brown, with a small but prominent black spot, which fades out with growth, on the anterior part of the dorsal fin.

Wolf eel, *Lycenchelys verrillii* (Goode and Bean)

The recorded range of the wolf eel, previously known only off the coasts of New England and Nova Scotia, has now been extended southward to the offing of New York (Beebe, 1929, p. 18).

The wolf eel is more common within the Gulf of Maine, in deep water, than was formerly supposed, for in the autumn and summer of 1928 and 1930 the *Albatross II* trawled 61 specimens, 6 to 6½ inches long, in the deep basin to the westward of Jeffreys Ledge, in about 90 fathoms of water. It was also found scattered over the central basin of the gulf, in July 1931, in 95 to 123 fathoms.

Silver hake, *Merluccius bilinearis* (Mitchill)

The wintering ground of the Gulf of Maine stock of silver hake has been the subject of so much speculation that the capture by the *Albatross II*, of many specimens between the offings of No Mans Land and off Cape Hatteras in depths ranging from 12 to 146 fathoms, in February 1930 at temperatures of 4.2° to 10.6° C. (39.5° to 51° F.), deserves mention. Such wide ranges of temperature indicate that the silver hake are well distributed on these offshore grounds during the winter.

Young fish are rarely found close to shore within the gulf. Offshore, however, the *Albatross II* and *Atlantis* have trawled large numbers between 2 and about 8 inches long in widely scattered localities and in depths ranging from 20 to 115 fathoms.

Measurements of young silver hake,[12] recently obtained in the Gulf of Maine indicate that a length of 6–7 inches is attained at about 1 year of age.

Pollock, *Pollachius virens* (Linnaeus)

Recent tagging experiments verify the earlier view that the pollock which appear in the cold months of the year off New York and New Jersey are winter migrants from the region of Nantucket Shoals. In general the pollock in the Gulf of Maine are not migratory although occasional fish may make long journeys.

Cod, *Gadus callarias* Linnaeus

Extensive tagging experiments (Schroeder, 1930) have proved that the appearance of cod in winter southward along the coasts of New York and New Jersey in commercial quantities represents a regular annual mass migration from Nantucket Shoals followed by a return migration in spring. But only scattering fish join this winter migration from the more northerly and easterly parts of the Gulf of Maine. It has been known that many of these cod spawn on the southern wintering grounds, but it was not until the spring of 1930 that large numbers of fry were obtained there. At that time (April) *Albatross II* trawled hundreds of fry 1½ to 2½ inches long on bottom, the most southerly catch being in latitude 36°21′ N.[13]

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[12] Several hundred specimens.

Haddock, *Melanogrammus aeglefinus* (Linnaeus)

The haddock, formerly unknown beyond the Straits of Belle Isle, in the western Atlantic, has now been reported from West Greenland (Jensen and Hansen, 1930, p. 52). From Icelandic waters comes a record of a giant haddock 44 inches long and weighing about 37 pounds (Thompson, 1929, p. 29).

Long-finned hake, *Urophycis chesteri* (Goode and Bean)

The capture of several specimens on the northern edge of Georges Bank in September 1929, in 85 to 100 fathoms, and of many to the westward and in the central basin of the Gulf of Maine the summer of 1931, in 70 to 140 fathoms, suggests that this species is more plentiful in the gulf than was previously supposed.

This hake is said to be a summer spawner but very little is known concerning its rate of growth, hence we report captures of 3 fish 57 to 71 mm on April 26, 1931, and of 16 fish of 74 to 110 mm taken late in July, suggesting that a length of 4 or 5 inches is reached at 1 year of age.

Spotted hake, *Urophycis regius* (Walbaum)

The scarcity of this hake within the Gulf of Maine is emphasized by the fact that not a single one was captured there in the numerous hauls made recently by the *Albatross II*. To the southward, however, many were trawled between Cape Hatteras and the offing of Delaware Bay in 5 to 45 fathoms (chiefly in less than 20 fathoms) from February to May 1930 and 1931.

Although the spotted hake reaches a length of at least 16 inches, large fish are relatively rare. The longest of about 600 specimens taken on 14 stations by the *Albatross II* was only 130 mm (5⅛ inches). In the largest catch (Apr. 8) the dominant size was 2 to 2½ inches.

Four-bearded rockling, *Enchelyopus cimbrius* (Linnaeus)

The rockling has recently (July 1931) been trawled in the central basin of the Gulf of Maine where it was expected, but heretofore unrecorded. The fact that one was taken in latitude 36°56′ N., off Cape Charles, Va., on February 10, 1930, in only 12 fathoms, shows that in the most southerly parts of its range, it is not restricted to deep water, as previously supposed.

Cusk, *Brosme brosme* (Müller)

A fish 40 inches long and weighing 27 pounds, trawled by *Albatross II* in the central part of the Gulf of Maine, in 120 fathoms, is the largest definitely recorded from the Gulf of Maine.

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[13] These were taken during the course of O. E. Sette's mackerel investigations.

Common grenadier, *Macrourus bairdii* Goode and Bean

Recent records show that the grenadier is comparatively common on muddy bottom in the gulf, at depths greater than about 90 fathoms and that it may occasionally be taken shoaler, for one was reported from the slope of Jeffreys Ledge in about 50 fathoms during March 1934. The capture of a ripe male in late September verifies the earlier suggestion that the grenadier is an autumn spawner. The largest fish taken by *Albatross II* was 16 inches long. This grenadier has now been taken as far eastward as the Grand Banks of Newfoundland (Nfld. Rpt., 1933 (1934), p. 116).

American plaice, *Hippoglossoides platessoides* (Fabricius)

Recent trawling by *Albatross II* and *Atlantis* proves this species to be generally distributed even in the deeper parts of the central basin of the gulf, to a depth of at least 120 fathoms. A specimen 15½ inches long caught off Montauk Point, N. Y., in 112 fathoms, February 6, 1930, is the most southerly and westerly record.

As this flounder is a spring spawner it may be assumed that bottom stages 69 to 80 mm long trawled off Cape Cod, May 1, were about 1 year old, and 85 to 118 mm fry found at several localities in July and August were between 1¼ and 1½ years old, those of 8–10 inches, 2¼ to 2½ years.

Four-spotted flounder, *Paralichthys oblongus* (Mitchill)

This flounder, formerly thought rare to the east of Cape Cod, has recently been found here and there on the southern half of Georges Bank. Previously known only as far southward as New York, many have been trawled by the *Albatross II* south to the Virginia Capes (lat. 36°45′ N.).

The fact that captures were made in 23 to 112 fathoms in February (7 stations), 31 to 52 fathoms in March (two stations), 10 to 85 fathoms in April (eight stations), 15 to 35 fathoms in May (four stations), 11 to 47 fathoms in June (five stations), and 41 fathoms in July (one station) indicates that it is present and widely distributed in this general depth zone the year round.

The capture of ripe specimens as late as mid-July shows that the breeding season is not limited to spring, as formerly supposed, but extends well into the summer.

Rusty dab, *Limanda ferruginea* (Storer)

Capture of a specimen, in the offing of Hog Island, Va. (lat. 37° 41′ N.) considerably extends the known range to the southward. The captures of young dabs 2 to 4 inches long in February (17 fish), 2¼ to 4½ inches in April (26 fish), 2⅓ to 5⅗ inches in May (10 fish), 3 to 5 inches in June (3 fish) and 3 to 6⅛ inches in July (13 fish) yield the first data as to rate of growth. According to this growth schedule the rusty dab reaches a length of approximately 5 inches at 1 year of age.

Winter flounder, *Pseudopleuronectes americanus* (Walbaum)

The recovery, off Chatham and on Nantucket Shoals, of winter flounders tagged and released at Woods Hole proves that some of them, at least, may wander for longer distances than previously supposed.

Georges Bank flounder, *Pseudopleuronectes dignabilis* Kendall

This flounder, previously known only from the Georges Bank area, is now reported from the eastern edge of the Scotian banks and the western part of the Grand Banks of Newfoundland (Nfld. Rept., 1934 (1935), p. 79).

Witch flounder, *Glyptocephalus cynoglossus* (Linnaeus)

The witch flounder has recently been found to be generally distributed in the central basin of the Gulf of Maine where the *Albatross II* and *Atlantis* trawled it down to 140 fathoms, in July 1931 and in August 1936, respectively. Goode and Bean's (1896, p. 433) record of it in latitude 34°39′ at a depth of 603 fathoms (omitted in Bigelow and Welsh, 1925) shows that it ranges southward to the offing of Cape Hatteras in deep water. But the most southerly record of it in shoal water is a specimen taken by *Albatross II* in 10 fathoms off Virginia (lat. 37°50′).

Many specimens from 3 to 5 inches and from 7 to 8½ inches long were taken from July to September suggesting that the witch reaches a length of about 4 inches at 1 year and about 8 inches at 2 years of age.

Gulf Stream flounder, *Citharichthys arctifrons* [14] Goode

This little flounder was formerly believed to reach a length of only about 4 inches but recently the *Albatross II* collected many specimens up to 7 inches long.

Recent trawling experience extends knowledge of its distribution by showing that it may occur as shoal as 12 fathoms, and that it finds its northeastern boundary off the southeastern slope of Georges Bank and its southwestern boundary off Cape Hatteras. Usually only a few specimens are taken in any given trawl haul, even further to the west and south where the species appears to be most common; hence, a catch of about 100 made by the *Albatross II*, off Montauk Point, N. Y., in 50 fathoms, is noteworthy.

Apparently, it spawns over a long season, from spring through summer, for we have found females with well-developed ovaries in February while Goode had ripe ones in September. Although the Gulf Stream flounder is not large enough and thus far has been found too scarce to be of commercial value, we can witness that it is excellent on the table.

American goosefish, *Lophius americanus* Cuvier and Valenciennes

Recent investigations by Berrill (1929) and by Procter et al. (1928) make it appear that the American goosefish, given as *Lophius piscatorius* in "Fishes of the Gulf of Maine" (Bigelow and Welsh, 1925, p. 524), is specifically distinct from the European.

Very small goosefish are seldom reported, hence captures of 1 of 10 inches in February, 1 of 10 inches in April, 2 of 7½ and 10 inches, respectively, in May, 3 of 6¾ to 9 inches in July, and 3 of 4 to 4¼ inches in August between latitudes 43°21′ N. and 37°36′ N. in depths ranging from 35 to 140 fathoms, are of interest.

Sargassum fish, *Histrio histrio* (Linnaeus)

A single specimen about 4¾ inches long, picked up in a purse seine near the surface over the west central part of Georges Bank, by the schooner *Old Glory* on September 15, 1930 (Firth, 1931, p. 14), extends the known range of this fish to the Gulf of Maine.

Deep-sea angler, *Mancalias uranoscopus* (Murray)

A 24½-inch specimen of this uncommon fish was trawled on Georges Bank February 9, 1927, by the fishing steamer *Ripple;* this is the only record of a member of this family (Ceratiidae) from New England waters (Parr, 1932, p. 12).

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Contribution No. 120

Reprinted from SCIENCE, November 13, 1936, Vol. 84,
No. 2185, pages 442–443.

PHOTOCHEMICAL OXIDATION OF AMMONIA IN SEA WATER[1]

PHOTOCHEMICAL transformations between ammonia, nitrite and nitrate have been frequently reported under a variety of conditions[2, 3, 4, 5]. Recently Drs. S. A. Waksman and C. L. Carey, of the Woods Hole Oceanographic Institution, and one of us (A.H.), carried out a number of qualitative tests for nitrite in sea water irradiated after the addition of nitrate and ammonia. These preliminary results, which will shortly be published, as well as the work of ZoBell[6] on the photochemical oxidation of ammonia, suggested a more quantitative study.

Accordingly, ammonium sulfate was added to sea water from various sources, and to distilled water, and determinations made for ammonia and nitrite before and after irradiation with ultra-violet light. Confirmation was so easily obtained of the change of nitrate to nitrite in sea water that further investigation of this was deemed superfluous for this preliminary investigation. Furthermore, the slow destruction of nitrite in sea water by ultra-violet light was conclusively shown, but the corresponding process in distilled water seemed much slower, even doubtful.

Finally, attention was entirely centered on the oxidation of ammonia to nitrite. Ammonia was determined by the method of Krogh,[7] which has been slightly modified to serve as a routine analytical method for sea water. Nitrite was determined colorimetrically by the well-known method of Griess.

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[1] Contribution No. 120 from the Woods Hole Oceanographic Institution.

[2] H. Thiele, *Ber. deutsch. chem. Ges.*, 40: 4914, 1907.

[3] B. Moore, *Proc. Roy. Soc.*, B., 90: 158, 1918.

[4] D. S. Villars, *Jour. Amer. Chem. Soc.*, 49: 326, 1927.

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[7] A. Krogh, *Biol. Bull.*, 67: 126, 1934.

The solution in each case was irradiated in a cell of 15 mm depth with crystalline quartz windows 70 × 16 mm, sealed on with picein. The light from a high pressure water-cooled quartz capillary mercury-vapor lamp,[8] operated at 150 v. and 3.5 amp., was concentrated on the exposure cell. The radiation from the lamp (1,950 to 9,000 Å) was of considerably higher intensity per unit of surface than that given by a commercial mercury-vapor lamp. Since the radiation passed through one cm of tap water, one fused quartz window and 25 cm of air, in addition to a crystalline quartz lens and window before entering the cell, it contained extremely little radiation below 2,200 Å.

The control cell was of construction identical to that of the exposure cell, but had glass windows and was painted black. The solutions in both cells were kept at 20° C. and stirred thoroughly.

Results showing the change of ammonia to nitrite are given in Table 1. All figures represent nitrogen in micrograms per liter.

In Sample 3 approximately one mg of ammonia-nitrogen was added per liter, but was not determined quantitatively, either before or after radiation. In Sample 8 so much of the solution had to be used for the ammonia analysis that there was only enough remaining for a qualitative test for nitrite, which was very distinctly positive. No. 10 was from a mixed sample taken from a number of sources, all below 1,000 meters in depth, and consequently with a high nitrate content. The fact that the nitrite produced exceeded the ammonia lost in this sample is evidently due to simultaneous reduction of nitrate.

It is to be observed that the photochemical oxidation of ammonia takes place in sea water but not in dis-

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[8] F. Daniels and L. J. Heidt, *Jour. Amer. Chem. Soc.*, 54: 2381, 1932.

TABLE 1

			Micrograms per liter		
Sample No.	Description	Time of irradiation	Ammonia-nitrogen	Nitrite-nitrogen	Ammonia loss
1.	Distilled water	0	890	0	
	$+ NH_3$	2 hr.	940	0	
2.	Distilled water	0	980	0	
	$+ NH_3$	2 hr.	940	0	
3.	Surface sea water	0	1000 ±	0	
	$+ NH_3$	1 hr.	....	112	
4.	Same	0	980	0	
		2 hr.	490	335	490
5.	Same	0	970	0	
		2 hr.	740	166	230
6.	Same	0	970	0	
		2 hr.	600	270	370
7.	Same, but radiated				
	through Uviol	0	960	0	
	filter	3½ hr.	780	35	180
8.	Surface sea water,				
	same as 3, 4, 5, 6, 7,	0	68	0	
	but no added NH_3	1½ hr.	26	+ +	
9.	Sea water from	0	850	0	
	wharf $+ NH_3$	1 hr.	670	125	180
10.	Deep sea water	0	940	0	
	$+ NH_3$	1 hr.	740	270	200*

* Nitrate content of this water was 265. All other samples nearly nitrate-free (10–25).

tilled water, confirming in quantitative form ZoBell's earlier observations.

Passing the radiation through a Uviol filter in No. 7 reduced its efficiency considerably, and the questions arising from this fact will be the subject of further study.

With the exception of this sample and No. 10, already mentioned, a relatively constant proportion (68 to 73 per cent.) of the ammonia is transformed into nitrite.

This whole work must be considered preliminary to a more complete study of the extraordinary conditions surrounding photochemical actions in sea water.

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Contribution No. 122

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An Ecological Aspect of the Gulf Stream*

THE view has been increasingly accepted, since first put forth by Nathansohn[1], that the fertility of the sea depends upon the restoration to the surface of plant nutrients such as phosphates and nitrates liberated by the decomposition of organic matter within its depths. In shallow coastal waters the turbulence due to wind and tide, aided in high latitudes by the instability resulting from cooling in winter, suffice to maintain this part of the nutritional cycle. In the deep sea, organic matter generated in the surface as the result of photosynthetic processes appears in large part to sink to great depths before being finally oxidized to its ultimate inorganic products. This is evidenced by the increasing concentration of nitrate and phosphate (and decreasing quantity of oxygen) which is observed until depths of 800–1,000 metres are reached.

Wattenberg[2] has recently listed four processes by which these materials are brought again to the surface in the Atlantic Ocean and thus made available for the organic cycle. These are: (1) upwelling resulting from offshore trade winds off the African coast; (2) upwelling of deep Atlantic water in the Antarctic; (3) upwelling in the boundary between currents as in the Arctic polar front; and (4) winter convection in high latitudes. The present note is intended to direct attention to an additional and hitherto unrecognized mechanism which would appear to accomplish the same end and particularly to maintain the high fertility of the waters of the eastern coast of North America.

In a paper entitled "The Dynamics of Steady Ocean Currents in the Light of Experimental Fluid Mechanics", Rossby[3] has shown that the Gulf Stream may be likened to a wake stream discharging into the upper layers of a stratified medium. A wake stream, which appears to be a divergent current, is actually drawing in water from the surroundings. In a stratified medium the boundary between the layers must dip down towards the right in the northern hemisphere, as the isopycnics are observed to do in sections across the Gulf Stream, and this dip is to be regarded as the result rather than the cause of the current flow. The compensating movements set up in the surroundings of a wake stream must have a component in the direction of the current itself on the right side. The Antilles current appears to be such a compensating current. On the left side, the compensating movements must appear as a counter current, represented by the slope water of the American coast.

It is brought out that the absorption of water into the wake stream must take place primarily along the right edge, and that water will be ejected from the wake stream into the counter current. It results that water may be transferred across the current from the open ocean basins to the right into the limited body of water to the left of the current. This lateral transport must take place principally along isopycnics, which are known to slope sharply as they cross the Gulf Stream. Water is thus carried upward as well as shoreward as the result of the primary stream.

The observations of Seiwell[4] on the distribution of oxygen and phosphate in the north Atlantic make it clear that the apparent site of maximal decomposition of organic matter lies much closer to the surface (250 metres) in the continental slope water than in mid-ocean (800 metres). Such a large difference cannot reasonably be ascribed to differences in the rate of sinking or of decomposition of organisms in the contrasted localities. The findings are, however, entirely consistent with the wake stream theory developed by Rossby, since on this view the slope water is derived in considerable part from water absorbed at a greater depth along the offshore edge of the Gulf Stream. The close correlation which may be observed in a section across the Gulf Stream between the conservative properties of temperature and salinity, on one hand, and the properties of biological origin such as oxygen, phosphate and nitrate concentration, on the other, suggests that the observed distribution of the latter is the result of hydrographic factors rather than biological action *in situ*. The products of decomposition which appear at a depth of 200–300 metres in the slope water may have been actually derived from a much greater depth in the open ocean.

Rossby's wake stream theory thus provides a mechanism for the transport of water rich in organic nutrients from the depths of the Atlantic basin on to the edge of the continental shelf. Here it comes within the influence of tidal mixing and winter convection, which complete the transport of nutrients to the surface. The latter stages in the process may be observed in the Gulf of Maine, into which slope water penetrates, and along the continental shelf[5]. Rossby's study suggests that the absorption of oceanic water into the Gulf Stream takes place chiefly south of the latitude of Chesapeake Bay ; the discharge of this water at a lesser depth occurs from Chesapeake Bay to at least Nova Scotia. If his theory is correct, he has discovered a mechanism on which the fertility of the waters of the Atlantic Coast of North America must largely depend.

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Harvard University,
Cambridge, Massachusetts.

[*] Contribution No. 122 from the Woods Hole Oceanographic Institution.

[1] A. Nathansohn, *Abhand. Konigl. sachs Gesel. der Wissensch. Leipsig*, **39**, 3 (1906).

[2] C. W. Correns, A. Defant, F. Gessner, W. Stahlberg V. Schubert, H. Wattenberg and B. Wüst, "Tiefseebuch" (Berlin, 1934).

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[5] H. B. Bigelow, "Papers in Physical Oceanography and Meteorology", **2**, No. **4**.

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Contribution No. 128

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Woods Hole Oceanographic Institution

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No. 2189, pages 537–538.

CONTAMINATION AND COMPACTION IN CORE SAMPLING

FOR a number of years marine sediments have been sampled by means of coring instruments of various types. The cores obtained have been sectioned; mechanical and chemical analyses have been made; and in some cases, micro-fossil studies have been undertaken. This detailed work has been accomplished with little regard for the contamination of the materials which may have taken place as the core sample was obtained. Also, the vertical extent of the material being dealt with before coring was not considered. Therefore, an investigation of this method of sampling seemed desirable.

An opportunity to carry out such a study was obtained during the summer of 1936 spent at the Woods Hole Oceanographic Institution with the helpful guidance of Mr. H. C. Stetson. The magnitude of the contamination taking place was determined by a number of simple laboratory experiments. Samples of a bright red clay, a fine green glauconitic sand and a buff-colored clay were slaked down and layered in a glass-sided aquarium tank, two and one half, by three, by two feet in dimension. The buff clay was placed on the bottom, the green sand over that, and the red clay as the surface material. Mechanical analyses were made of the fine green sand and the buff clay, which gave median diameters of .129 mm for the sand and .062 mm for the clay. The red clay presented a problem in obtaining deflocculation of the finer particles; and as time was short, the median diameter was not determined. However, the texture appeared to approximate that of the buff clay. Cores were then taken in these layered sediments by plunging the instruments in by hand. The two types of instruments which are most commonly used were tested, a brass tube, one and one half inch in diameter, and a three quarter inch glass tube which is inserted in a metal pipe when in actual use. In every case observed the soft red clay surface material was found to have smeared the entire length of the outer surface of the core, which left only a part of this material in its original position at the upper surface of the core. The base of the green glauconite layer showed a sharp, clean-cut contact, while the top of this green glauconite layer presented a zone of contamination from one half to one inch wide in which the red clay was mixed with green glauconite grains.

The second phase of the problem, the compaction which results from the instrument plunging into the sediments, was studied by actually obtaining core samples of the numerous types of bottom materials present in the vicinity of Woods Hole and Massachusetts Bay. The outer surface of the coring instrument was carefully cleaned and coated with shellac before each core was taken. In that manner the exact depth of penetration of the instrument could be determined as particles of the sediment clung fast to the sticky shellac. The length of the core was determined before removing it from the instrument, and the amount of compaction could then be calculated. The figures given below in Table I are averages of not less than six cores taken in each type of material. The fact that the relative depth of penetration and the

TABLE I

ILLUSTRATING THE COMPACTION TAKING PLACE DURING CORE SAMPLING. PENETRATION WAS DETERMINED BY SHELLACKING OUTER SURFACE OF CORING INSTRUMENT

Character of bottom	Penetration	Length of core	Compaction
Soft mud over sand	5′ 11.25″	3′ 2.85″	2′ 8.4″
Soft mud	6′ 8.6″	3′ 2.4″	3′ 6.2″
Soft mud (Lowering tube slowly)	4′ 1.3″	1′ 10.6″	2′ 2.7″
Sand bottom	1′ 8.1″	1′ 1.6″	6.5″
Sandy silt	2′ 9″	1′ 5″	1′ 4″

length of core remained constant in a particular type of sediment indicated that a true picture of the compaction taking place was obtained.

Conclusions

The results obtained from the experiments on contamination suggest three points which should be observed when taking samples from a core.

(1) The outer surface of the core should be eliminated from the sample. This may be done by simply drying the core and scraping off the outer surface or slicing the core lengthwise and removing the sample from the center.

(2) The presence of the zone of contamination between the layers of fine sand and the red clay indicated the possibility of contamination at the contact of two sediments of varying texture. Taking samples close to such a contact should be avoided.

(3) If the surface material is of fine texture any analyses such as a mechanical analysis of the material being deposited under present-day conditions or the determination of the food value for sea life in the material at the bottom of the sea could not be done accurately by analyzing the material at the top of such a core sample. The surface material would be smeared down the length of the core and compacted.

From the figures given above it is clear that the vertical extent of material being dealt with in a core is much greater than the apparent extent shown by the length of the core itself. The exact extent, however, can not yet be shown; as it seems reasonable to believe that the material say two feet below the surface will compact less than the material at the surface as the instrument penetrates it. Thus, the true vertical extent of the material dealt with could be determined only after a curve showing the decrease of compaction taking place in a coring tube with depth has been established.

William F. Wrath

University of Illinois

Report for the year 1935

THE
WOODS HOLE OCEANOGRAPHIC
INSTITUTION

REPORT FOR THE YEAR
1935

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I

TRUSTEES

(As of December 31, 1935)

To serve until 1939

Iasiah Bowman, Johns Hopkins University, Baltimore, Md.
E. G. Conklin, Princeton University, Princeton, N.J.
Alexander Forbes, Harvard Medical School, Boston, Mass.
Ross G. Harrison, Yale University, New Haven, Conn.
Frank R. Lillie, University of Chicago, Chicago, Ill.
Harlow Shapley, Harvard University, Cambridge, Mass.

To serve until 1938

Charles Francis Adams, Boston, Mass.
Thomas Barbour, Museum of Comparative Zoölogy, Cambridge, Mass.
Benjamin M. Duggar, University of Wisconsin, Madison, Wis.
John A. Fleming, Carnegie Institution, Washington, D.C.
Frank B. Jewett, New York, N.Y.
Elihu Root, Jr., New York, N.Y.

To serve until 1937

Marion Eppley, Newport, R.I.
The Hydrographer, United States Navy Department, for the time being.
T. H. Morgan, California Institute of Technology, Pasadena, Calif.
R. S. Patton, U. S. Coast & Geodetic Survey, Washington, D.C.
B. W. St. Clair, Cambridge, Mass.
Commander Edward H. Smith, U. S. Coast Guard, Woods Hole, Mass.

To serve until 1936

William Bowie, U. S. Coast & Geodetic Survey, Washington, D.C.
A. G. Huntsman, University of Toronto, Toronto, Canada.
Alfred L. Loomis, Tuxedo Park, New York.
Henry L. Shattuck, Boston, Mass.
T. Wayland Vaughan, Scripps Institution of Oceanography, La Jolla, Cal.

Ex officio

Henry B. Bigelow, Museum of Comparative Zoölogy, Cambridge, Mass.
Lawrason Riggs, Jr., New York, N.Y.

OFFICERS

Frank R. Lillie, President of the Corporation, University of Chicago, Chicago, Ill.
Lawrason Riggs, Jr., Treasurer, 120 Broadway, New York, N.Y.
Henry B. Bigelow, Clerk of the Corporation, Woods Hole, Mass.

II

MEMBERS OF THE CORPORATION

(As of December 31, 1935)

Charles Francis Adams, Boston, Mass.
Thomas Barbour, Museum of Comparative Zoölogy, Cambridge, Mass.
Henry B. Bigelow, Museum of Comparative Zoölogy, Cambridge, Mass.
Isaiah Bowman, Johns Hopkins University, Baltimore, Md.
E. G. Conklin, Princeton University, Princeton, N.J.
Benjamin M. Duggar, University of Wisconsin, Madison, Wis.
Marion Eppley, Newport, R.I.
John A. Fleming, Carnegie Institution, Washington, D.C.
Ross G. Harrison, Yale University, New Haven, Conn.
A. G. Huntsman, University of Toronto, Toronto, Canada
The Hydrographer, U. S. Navy Department, for the time being, Washington, D.C.
Frank B. Jewett, New York, N.Y.
Frank R. Lillie, University of Chicago, Chicago, Illinois
Alfred L. Loomis, Tuxedo Park, N.Y.
T. H. Morgan, California Institute of Technology, Pasadena, Calif.
R. S. Patton, U. S. Coast & Geodetic Survey, Washington, D.C.
Lawrason Riggs, Jr., New York, N.Y.
Elihu Root, Jr., New York, N.Y.
B. W. St. Clair, Cambridge, Mass.
Harlow Shapley, Harvard University, Cambridge, Mass.
Henry L. Shattuck, Boston, Mass.
Commander E. H. Smith, U. S. Coast Guard, Woods Hole, Mass.
T. Wayland Vaughan, Scripps Institution of Oceanography, La Jolla, Calif.

III

REPORT OF THE TREASURER

May 26, 1936

To the Members and Trustees of the
Woods Hole Oceanographic Institution:

Gentlemen:

The accounts of the Treasurer to the end of the fiscal year February 29th, 1936, have been audited by Messrs. Stagg, Mather & Hough, public accountants, and a copy of their report is on file in the office of the Institution.

At the time of the organization of the Institution the Rockefeller Foundation in addition to the Endowment Funds and Plant Funds contributed by it, made a grant of Five Hundred Thousand Dollars ($500,000) or so much thereof as might be necessary for current expenses over a period of ten (10) years commencing March 1, 1930, payments in any one year not to exceed Fifty Thousand Dollars ($50,000). This arrangement has been cancelled by agreement between the Foundation and the Institution and in its place the Foundation has added One Million Dollars ($1,000,000) to the Endowment Funds of the Institution, which was paid in October 1935, as follows:

In stock	$ 349,711.00
In bonds	349,987.50
In accrued interest on bonds	244.00
In cash	300,057.50
	$1,000,000.00

The Treasurer wishes to acknowledge the invaluable services of the Finance Committee consisting of Messrs. Adams, Shattuck and Root in connection with the investment and reinvestment of the Endowment Funds. The duties of the Finance Committee have been exceptionally heavy this year due to the receipt of the additional Endowment Funds and to the calling of many issues held by the Institution.

Following are summaries of the various accounts:

PLANT ACCOUNT

Gift from the Carnegie Corporation for purchase of land	$ 27,542.13
Endowment by Rockefeller Foundation	580,100.00
Appropriated from current funds	26,106.71
Reserve for depreciation (Reserve for periodical replacements) appropriated from current funds	18,972.11

Laboratory plant:		
Land	$ 27,072.32	
Building	323,213.12	
Laboratory equipment	21,361.93	
Crew room equipment	557.95	
Library	9,000.00	
Ship *Atlantis*		
Construction	218,674.47	
Equipment	27,298.50	
Asterias construction and equipment	6,570.55	
Depreciation fund (reserve for periodical replacements):		
Bonds	7,000.00	
Cash	11,972.11	
	$652,720.95	$652,720.95

ENDOWMENT FUNDS

Received from Rockefeller Foundation for Endowment Funds		
General		$2,000,000.00
For upkeep of plant		419,419.96
		$2,419,419.96
Less—Unamortized losses on securities sold		4,696.05
		$2,414,723.91
Reserve for amortization of bond premiums	$10,983.69	
Less—Losses sustained on securities called or sold chargeable to the reserve	5,007.25	5,976.44
		$2,420,700.35
This is represented by the following investments at cost:		
Bonds (market value $1,511,198.75)	$1,452,622.95	
Stocks (market value $1,019,878.25)	959,432.49	
	$2,412,055.44	
Cash in bank	1,668.42	
Receivable (consisting of appropriation since received and amount transferable from accounts payable)	6,976.49	
	$2,420,700.35	$2,420,700.35

A full list of the securities will be found in the Auditors' report.

RESERVE FUND

Anonymous gift of March 14, 1931, in cash and securities	$30,000.00

Accumulated income of prior years	2,805.91
Income of current year	611.74
	$33,417.65
Appropriation of prior years	2,000.00
	$31,417.65

GENERAL ACCOUNT

For the period from March 1, 1935 to February 29th, 1936:

Income:			
From the Rockefeller Foundation for current expenses for the year ended February 29, 1936			$41,732.49
Interest from investments			53,217.38
Dividends from investments			22,414.25
			$117,364.12
Less —Custodian fees			1,097.15
Total Income			$116,266.97
Expenses:			
Upkeep of Plant			
Upkeep of building & grounds		$6,344.86	
Upkeep of *Atlantis*		8,713.18	
Upkeep of *Asterias*		164.23	
Insurance		6,897.52	
Reserve for depreciation		6,000.00	
		$28,119.79	
Operating Expenses:			
Operation of *Atlantis*	$29,086.48		
Operation of *Asterias*	820.20		
Scientific salaries	27,865.22		
Scientific supplies and equipment	2,945.46		
Travelling expense	574.44		
Publications	3,756.14		
Administration	7,224.66		
Amortization of bond premiums	7,693.83		
Contribution to retirement fund	1,753.87	$ 81,720.30	
		$109,840.09	
Expenditure for Permanent Plant Additions:			
Additions to library		$ 1,000.00	
		$110,840.09	$116,266.97
Excess of income over expenditures		$ 5,426.88	
		$116,266.97	$116,266.97

RETIREMENT FUND

In June 1934, a system of retiring allowances, participation in which is voluntary, was established. At the end of the fiscal year there was in the Savings Bank accounts to the credit of the seventeen (17) participants, the sum of, $6,197.75 of which $3,050.46 was deducted from salaries, $3,050.45 was contributed by the Institution, and 96.84 is interest from the Savings Bank.

CURRENT POSITION

The situation on March 1, 1936, the beginning of the present fiscal year, was as follows:

Current Assets		*Current Liabilities*		
Cash	$8,238.27	Accounts payable		$1,733.09
		Accrued salaries		62.50
Interest receivable (accrued interest on bonds purchased)	1,602.49	Current Surplus and reserve for "Working Balance":		
		Reserve for Working Balance		5,000.00
		Current Surplus—Deficit at Feb. 28, 1935	*$2,381.71*	
		Deduct—Excess of income over expenditures, year ended February 29, 1936	$5,426.88	
				3,045.17
	$9,840.76			$9,840.76

Respectfully submitted,
LAWRASON RIGGS, JR.
Treasurer.

IV

SIXTH ANNUAL REPORT OF THE DIRECTOR FOR THE YEAR 1935

BY HENRY B. BIGELOW

Equipment

The chief mechanical addition to our equipment on shore was the installation, in the pump house, of a motor generator to supply electric current to "Atlantis" while she is at the dock. In the laboratory building, the reading room has been comfortably furnished to serve as a lounge and the kitchenette made available to all scientific workers in the Institution, filling a long felt want; and a large scale chart of the Gulf of Maine has been installed in the chart room in addition to the Atlantic chart, so that all "Atlantis" stations can now be shown.

A new scavenger pump was purchased and installed in the main engine on "Atlantis," and the main governor, which had been giving trouble, was replaced with one of different design without marked advantage. A survey of the hull and machinery was made by Lloyds.

Accidents on "Atlantis" included a bent propeller blade, and damage to the steering gear, mishaps which did not seriously delay her operations.

There have been no important alterations on "Asterias." Both vessels are in excellent condition.

Five current meters of new design were manufactured for use in the horizontal closing nets. An improved heavy dredge was constructed for Mr. Stetson's work; 22,000 feet of new hydrographic wire, and two new psychrometers were purchased; an Ekman current meter was assembled from odd parts; and a pump-filter installed on "Asterias" for collecting plankton. Routine purchases of scientific supplies need no special mention.

The U. S. Coast Guard loaned us a one-meter range finder which was used on "Atlantis" in connection with Dr. Watson's current-meter work.

A ship theodolite, borrowed two years ago, was returned to the Navy Department.

Acknowledgments

Furnishings for the lounge and photographs for the Institution's collection of pictures were donated by various members of the Laboratory.

The U. S. Coast and Geodetic Survey and the U. S. Hydrographic Office assisted us in providing charts.

While "Atlantis" was working on Georges Bank on June 14 the otter trawl was tangled around her propeller making it impossible to use the engine until the propeller was cleared. "Atlantis" could have returned to port under sail, but as the U. S. Coast Guard cutter "Faunce" was nearby at the time, Captain McMurray was glad to accept a tow from her to Boston. Again on July 8 while "Atlantis" was at anchor in Nantucket Sound, off Monomoy, one of our seamen was taken suddenly ill. The Monomoy Station sent out their surf boat and took him ashore, whence he returned to Woods Hole. For these services, we are greatly indebted to the Coast Guard and I have transmitted our thanks to the Commandant.

Library

Our general relationship with the Marine Biological Laboratory continues as heretofore. Our contribution to the Library for the fiscal year 1935–1936 was $1000, spent on subscriptions to serials, filling out back sets of the latter, purchasing new books and binding serials.

We now receive about 200 titles yearly by gift or exchange, which are deposited in the library.

Personnel

There have been no changes among the staff.

It was my sad duty to report that on March 16th, Delano Potter, second officer, was instantly killed in an automobile accident in Pensacola, Florida, T. S. Greenwood, technician, so badly injured that he died in the hospital a few hours later, and Marshall Bishop, assistant to Professor Parr, less seriously injured. As they were not on duty at the time, there was no financial liability for the Institution. To fill the vacancies, Knute Nielsen, former boatswain, was promoted to second officer and Harold C. Williams appointed wireless operator.

"Asterias" was again in charge of Captain G. W. Carlson, and Charles Butcher II served as engineer. Mr. Iselin continues to supervise the operation of both our vessels.

The same sum, $4000, was appropriated for Fellowships as in previous years, stipends to range from $60. per month to $100. per month for graduate students.

The following appointees worked at the Laboratory during the summer: Victor M. Emmel, John L. Fuller, Margaret Hotchkiss, Jack L. Hough, Frank H. Johnson, Bostwick H. Ketchum, Benjamin B. Leavitt, Lois Lillick, Raymond B. Montgomery, Wilson M. Powell, Jr., Edward Roos, Frederick K. Sparrow, Jr., John H. Welsh, Allyn B. White.

A grant was also made enabling Dr. Kurt Buch, Professor of Chemistry at Åbo Academy, Åbo, Finland, and chemist at Havsforsknings Institutet, Helsingfors, Finland, to spend the summer at the Institution.

The following visiting investigators worked at the Institution: A. P. Crary, Gardner Emmons, Dr. Maurice Ewing, Dr. R. M. Field, Dr. Charles J. Fish, Dr. Philip H. Mitchell, Dr. G. H. Parker, Dr. H. M. Rutherford, Louis A. Toth, Dr. Morgan Upton, Dr. Charles B. Wilson and Donald J. Zinn. There were also eleven assistants to the staff, of whom two worked as volunteers, and one laboratory technician.

The following were represented in the laboratory and on "Atlantis" cruises for this year; Åbo Academy, Finland, Barnard College, Berkshire School, Bass Biological Laboratory, Brown University, Byrd Antarctic Expedition, Dartmouth College, Flower Medical College, Harvard University, International Ice Patrol, Lehigh University, Massachusetts Institute of Technology, Massachusetts State Teachers College, University of Chicago, University of Cincinnati, University of Rochester, U. S. Coast Guard and Yale University.

Ninety-five persons, of all categories, worked at the Institution during the past year.

Foreign Travel by the Staff

Dr. Waksman and Professor Rossy both went to Europe in July, the former to attend the Sixth International Soil Conference at Oxford, England, and the International Botanical Congress at Amsterdam, the latter to visit in Sweden.

In May the Director attended the annual meeting of the International Council for the Exploration of the Sea, in Copenhagen.

Publication

Numbers 3 and 4 of Volume III and numbers 1 and 2 of Volume IV "Papers in Physical Oceanography and Meteorology" were published.

Between January 1, 1935 and December 31, 1935, the following numbered contributions appeared from the Institution:

No. 24. Seiwell, H. R. The Annual Organic Production and Nutrient Phosphorus Requirement in the Tropical Western North Atlantic. Jour. du Conseil, Vol. 10, no. 1, pp. 20–32. 1935.

No. 52. Stetson, H. C. and Marshall Schalk. Marine Erosion of Glacial Deposits in Massachusetts Bay. Jour. Sedimentary Petrology, Vol. 5, No. 1, pp. 40–51. 1935.

No. 57. Waksman, Selman A. and Cornelia L. Carey. Decomposition of Organic Matter in Sea Water by Bacteria. I. Bacterial Multiplication in Stored Sea Water. Jour. Bacteriology, Vol. 29, No. 5, pp. 531–543. 1935.

No. 58. Oster, R. H. and G. L. Clarke. The Penetration of the Red, Green and Violet Components of Daylight into Atlantic Waters. Jour. Optical Soc. Amer., Vol. 25, No. 3, pp. 1–16. 1935.

No. 59. Leavitt, Benjamin B. A Quantitative Study of the Vertical Distribution of the Larger Zoöplankton in Deep Water. Biol. Bull., Vol. LXVIII, No. 1, pp. 115–130. 1935.

No. 60. Parker, G. H. The Electric Stimulation of Chromatophoral Nerve-Fibers in the Dogfish. Biol. Bull. Vol. LXVIII, No. 1, pp. 1–3. 1935.

No. 63. Seiwell, Gladys Eddy. Note on Iron Analyses of Atlantic Coastal Waters. Ecology, Vol. XVI, No. 4, pp. 663–664. 1935.

No. 64. Seiwell, H. R. The Phosphorus Cycle in the Western Basin of the North Atlantic. Part I. The Distribution of Phosphate and Organic Phosphorus. Papers in Physical Oceanogr. and Meteorol., Vol. 3, No. 4, pp. 1–56. 1935.

No. 66. Clarke, G. L. and S. S. Gellis. The Nutrition of Copepods in Relation to the Food-Cycle of the Sea. Biol. Bull., Vol. LXVIII, No. 2, pp. 231–246. 1935.

No. 67. Renn, Charles E. A Mycetozoan Parasite of *Zostera marina*. Nature, Vol. 135, p. 544. 1935.

No. 68. Waksman, Selman A. and Cornelia L. Carey. Decomposition of Organic Matter in Sea Water by Bacteria. II. Influence of Addition of Organic Substances upon Bacterial Activities. Jour. Bacteriology, Vol. 29, No. 5, pp. 545–561. 1935.

No. 69. Gran, H. H. and Trygve Braarud. A Quantitative Study of the Phytoplankton in the Bay of Fundy and the Gulf of Maine (including Observations on Hydrography, Chemistry and Turbidity). Jour. Biol. Bd. Canada, Vol. 1, No. 5, pp. 279–467. 1935.

No. 70. Bigelow Henry B. and Mary Sears. Studies on the Waters of the Continental Shelf, Cape Cod to Chesapeake Bay. II. Salinity. Papers in Physical Oceanogr. and Meteorol., Vol. 4, No. 1, pp. 1–94. 1935.

No. 71. Rossby, C.-G. and R. B. Montgomery. The Layer of Frictional Influence in Wind and Ocean Currents. Papers in Physical Oceanogr. and Meteorol., Vol. 3, No. 3, pp. 1–101. 1935.

No. 74. Mitchell, Philip H. and Ivon R. Taylor. The Dissociation Constant of Cresol Red in Sea Water. Jour. du Conseil, Vol. 10. No. 2, pp. 169–172. 1935.

No. 75. Irving, L., D. Y. Solandt and O. M. Solandt. Nerve Impulses from Branchial Pressure Receptors in the Dogfish. Jour. Physiol., Vol. 84, No. 2, p. 187. 1935.

No. 76. Stetson, H. C. Bed-Rock from the Continental Margin on Georges Bank. Trans. Am. Geophys. Union, Sixteenth Ann. Meeting, pp. 226–228. 1935.

No. 77. Seiwell, H. R. Phosphate in the Western Basin of the North Atlantic. Nature, Vol. 136, p. 206. 1935.

No. 79. Keys, Ancel, E. H. Christensen, and August Krogh. The Organic Metabolism of Sea-water with Special Reference to the Ultimate Food Cycle in the Sea. Jour. Mar. Biol. Assoc., Vol. XX, No. 2, pp. 181–196. 1935.

No. 87. Rakestraw, Norris W. and Henry E. Mahncke. Boron Content of Sea Water of the North Atlantic Coast. Ind. and Eng. Chemistry, Vol. 7, p. 425. 1935.

No. 89. Wald, George. The Visual Purple System in Marine Fishes. Nature, Vol. 136, p. 913. 1935.

The bound volume of "Collected Reprints" for 1934 was distributed in May. The annual report for 1934 was printed, and the physical and chemical data from "Atlantis" stations for the year 1934 were forwarded to the International Council for the Exploration of the Sea for publication in their Bulletin Hydrographique for 1934.

Coöperation

During the winter of 1935 "Atlantis" worked in the Gulf of Mexico, continuing our coöperative program with Bingham Oceanographic Foundation of Yale University, the Foundation again contributing $1,500 toward the expenses. Professor Parr acted as scientist-in-charge, with Marshall Bishop, M. D. Burkenroad and Y. Olson acting as his assistants.

During the month of June and again in December "Atlantis" was put at the disposal of the U. S. Bureau of Fisheries for haddock investigations on Georges Bank, Mr. W. C. Herrington of the Bureau in charge, the Bureau assisting by supplying fuel oil for the two cruises.

Laboratory provision for the International Ice Patrol Service continues, as does operation of the tide gauge for the Coast and Geodetic Survey. Certain routine data are regularly forwarded to the Director of Fisheries Research at St. John's, Newfoundland, to the International Hydrographic Bureau at Monaco and to the U. S. Hydrographic Office.

Field Work

During the year "Atlantis" made the following cruises:

Cruise 41: January–April; Gulf of Mexico.
Cruise 42: May; Gulf of Maine.
Cruise 43: June; Georges Bank for U. S. Bureau of Fisheries.
Cruise 44: July; off Cape Cod.
Cruise 45: July; South from Woods Hole.
Cruise 46: August; Continental Shelf.
Cruise 47: August; Gulf of Maine.
Cruise 48: August–September; South from Woods Hole.
Cruise 49: September–October; off Newfoundland.

Cruise 50: October–November; off Virginia Capes.

Cruise 51: November; Gulf of Maine.

Cruise 52: November–December; Georges Bank for U. S. Bureau of Fisheries.

Summary of observations

Total distance sailed	20,829 miles
Number of days at sea	246
Deep stations	77
Shallow stations	82
Trawling stations	154
Long Anchor stations	1
Temperature, Salinity and Oxygen	1,598
Other chemical determinations	1,200
Horizontal tows with closing nets	48
Light intensity stations	2
Bacteriological stations	23
Mud cores and bottom samples	43

"Asterias" was occupied chiefly in connection with the investigations of Dr. Clarke, Mr. Hough, Miss Lillick, Dr. Powell and Dr. Renn.

Staff Meetings

Continuing our previous custom staff meetings were held weekly during the active season, with the following list of speakers: Dr. Kurt Buch, Dr. George L. Clarke, Bostwick H. Ketchum, Benjamin B. Leavitt, Raymond B. Montgomery, Dr. Alfred C. Redfield, Dr. Charles E. Renn, S. Edward Roos, Prof. C.-G. Rossby, H. R. Seiwell, O. E. Sette, Henry C. Stetson, Dr. E. E. Watson, Dr. John H. Welsh.

Financial

The original grant of the Rockefeller Foundation to the Woods Hole Oceanographic Institution included an annual payment of $50,000 to continue for a period of ten years which terminates in 1940. Although no definite commitment was made, it has been our hope that on the termination of this grant the Foundation would replace it by the payment of additional endowment of equivalent capital value.

During the winter of 1935, changes in policy made the Foundation desire to terminate their financial obligations to the Institution. Accordingly on April 10, 1935, the Trustees of the Rockefeller Foundation voted

> "to appropriate the sum of $1,000,000 to the Woods Hole Oceanographic Institution for endowment, upon condition that the Institution shall agree to cancel as of the date of such contribution to endowment the Foundation's present appropriation to current maintenance."

And we were informed of their hope that such cancellation might take place within the year 1935.

After weighing the matter carefully, your President, Treasurer and Director recommended that the offer be accepted, for while the income from the new endowment would be less than the annual grant, acceptance would make the Institution permanently independent of outside sources. In accordance with this recommendation, the Executive Committee unanimously voted to accept the offer and the Rockefeller Foundation was so informed. This action was approved by the Trustees at the meeting on August 15th. The new endowment was paid over in October.

Amplifying the Treasurer's report, the following items may be of interest: the cost of maintaining and operating "Atlantis," including replacements, for the fiscal year 1935-1936 (exclusive of insurance) was $37,800, or an average of about $153 for each day at sea. The cost of operating "Atlantis" continues to average about $3,000 a month as previously.

In my last report I mentioned the increasing cost of all commodities. Fortunately for us there has been but little change in this respect the last year.

Scientific Program

The general division of our scientific program under direction of the members of the staff has proved productive. The visiting investigators either coöperate with the staff or carry on investigations in related fields. The activities of the various workers during the summer may be summarized as follows:

Ocean Physics and Meteorology

Preparation of report on hydrology of Northwest Atlantic and Labrador Sea, based on U. S. Coast Guard cruises of 1928, 1933 and 1934; E. H. Smith.

Preparation of oceanographic report of International Ice Patrol of 1934; Floyd M. Soule.

Preparation of report on Circulation of the Western North Atlantic, based on "Atlantis" cruises; C. Iselin.

Preparation of report on Circulation in the Bay of Fundy, calculations of the interchange of waters through the deep channels of the

Gulf of Maine, and experiments, from "Atlantis," with current meters; E. E. Watson and M. Watson.

Simultaneous measurements of humidity at various heights from 1 to 40 meters above sea surface, the data to be used to determine evaporation; also measurements of wind velocity at different heights above the sea surface; C. G. Rossby and R. B. Montgomery.

Analysis of movements of air masses along the coast and over the neighboring ocean; Gardner Emmons.

Measurements of reflection of light from sea surface, as related to absorption of light-energy by the water; George L. Clarke, Wilson M. Powell, Jr.

Physical and Biological Chemistry of Sea Water

Investigations on Phosphorus and Oxygen distribution in water and sediments of the North Atlantic and in the Caribbean, based on "Atlantis" cruises; H. R. Seiwell, Gladys Seiwell and Allyn White.

Standardization of indicators for measuring alkalinity of sea water; Philip H. Mitchell, Francis Maynard.

Study of nitrogen gas, nitrogen compounds, and iron in sea water; N. W. Rakestraw, Henry Mahncke and Victor M. Emmel.

Measurements of CO_2 tension in sea water, and comparison of methods for determining alkalinity; Kurt Buch.

Factors determining distribution of oxygen in the Gulf of Maine; Alfred C. Redfield.

Marine Bacteriology

Investigations of a) availability of suspended and dissolved organic matter in sea water; b) rôle of bacteria in phosphorus cycle in the sea; c) correlation between nitrogen and carbon cycles in the sea; and d) wasting disease of eel grass (*Zostera marina*); Selman A. Waksman, Charles E. Renn, Theone Cordon.

Measurements of electric potential in sea water; Wm. A. Burrows.

Oxygen consumption and metabolism of marine bacteria; Frank H. Johnson.

Census of bacterial population in sea water, and relationship of bacteria to the nitrogen cycle; Margaret Hotchkiss.

Submarine Geology and Topography

Preparation of report on fossiliferous rocks and sediments dredged from walls of the submarine canyons of Georges Bank in 1934, and similar dredging in the submarine canyons to the southward during the summer; Henry C. Stetson, Marshall Schalk.

Distribution of bottom deposits of Cape Cod Bay, and of the

Cape Cod sands in relation to the action of waves and currents; Jack L. Hough.

Preparation of bathymetric chart of Ross Sea, and depth-plotting for South Pacific, from echo soundings obtained on the last Byrd Antarctic Expedition; E. Roos.

First trials in deep water of a coring tube operated by an explosive charge, designed to obtain longer cores than had heretofore been taken; C. L. Piggot.

A seismic profile across the continental shelf off Chesapeake Bay by the adaption of the existing land technique to marine conditions; Maurice Ewing, R. M. Field, H. M. Rutherford, A. P. Crary.

Plankton Studies

Relative importance of various groups of microörganisms as food for oceanic copepods; George L. Clarke, John L. Fuller, Sidney Cobb.

Regional and seasonal survey of phytoplankton of Vineyard Sound; Lois Lillick.

Survey of zoöplankton of neighboring waters in relation to tide, season and so forth; George L. Clarke, Donald Zinn.

Preparation of reports on zoöplankton of Gulf of Maine and Bay of Fundy, based on field work in 1931–1933; Charles J. Fish. Preparation of report on zoöplankton of continental shelf waters, Cape Cod-Chesapeake Bay; Mary Sears.

Quantitative study of vertical distribution of pelagic animals, in the Atlantic basin, based on hauls with closing nets from "Atlantis"; Benjamin B. Leavitt.

Physiological Studies

Metabolism of diatoms; Bostwick H. Ketchum, Homer P. Smith.

Experiments on correlation between rate of growth of scales and increase in body-length of cod, at different temperatures; Wm. C. Schroeder.

A study of the rôle of changing temperature in the seasonal migration of Scup and Mackerel; Morgan Upton.

Investigation of blood-flow through the kidney, in the toadfish; Louis Toth.

Color changes in two species of dogfish in relation to nerves; G. H. Parker.

Diurnal changes in eye pigments of lobster, and eyes of deep sea crustacea; John H. Welsh.

Miscellaneous

Fungi parasitic on marine diatoms; Frederick K. Sparrow, Jr.

Examination of mud and sand-living copepods from northern part of the Gulf of Maine; C. B. Wilson.

V

STAFF

(As of December 31, 1935)

Henry B. Bigelow, Professor of Zoölogy, Harvard University, Director

Cornelia L. Carey, Barnard College, Research Associate in Marine, Bacteriology

George L. Clarke, Tutor and Instructor, Harvard University, Junior Biologist

Columbus Iselin, Assistant Curator of Oceanography, Museum of Comparative Zoölogy, Research Associate in Physical Oceanography

A. E. Parr, Curator of the Bingham Oceanographic Collection, Yale University, Research Associate in Oceanography

Norris W. Rakestraw, Associate Professor of Chemistry, Brown University, Research Associate in Physical Chemistry

Alfred C. Redfield, Professor of Physiology, Harvard University, Senior Biologist

C. E. Renn, Tutor and Instructor, Harvard University, Junior Marine Bacteriologist

C. G. Rossby, Professor of Meteorology, Massachusetts Institute of Technology, Oceanographer

H. R. Seiwell, Investigator in Oceanography

Floyd M. Soule, Senior Physical Oceanographer, U. S. Coast Guard, Research Associate in Oceanography

Henry C. Stetson, Assistant Curator in Paleontology, Museum of Comparative Zoölogy, Research Associate in Submarine Geology

Selman A. Waksman, Microbiologist, New Jersey Agricultural Experiment Station, Marine Bacteriologist

E. E. Watson, Lecturer in Physics, Queen's University, Research Associate in Physical Oceanography

Captain Sir Hubert Wilkins, Research Associate in Oceanography

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William C. Schroeder, Business Manager

Miss Virginia B. Walker, Secretary and Administrative Assistant

William Schroeder, Superintendent of Buildings and Grounds

APPENDIX

Reports of progress by investigators working at the Institution during 1935.

EFFECT OF TEMPERATURE ON GROWTH OF COD, AND OF THEIR SCALES

HENRY B. BIGELOW AND WILLIAM C. SCHROEDER

During the summer of 1935 an experiment was conducted in the aquarium room of the Institution to determine what effects, if any, temperature has on the growth of cod, and of the scales.

Three cod were held in water of a seasonal temperature, while four were kept in chilled water. Measurements and scale samples were taken periodically, and record kept of food consumed. The experiment, beginning May 10, continued without interruption until August 19th, when the "warm" water fish died because of a mishap to the water system. Two of the cold water fish were then transferred to the warm tank and this condition continued until September 24th when a further mortality necessitated discontinuing the experiment.

The colder temperature fluctuated, because of mechanical difficulties with the cooling system, between 7.6° and 4.1° C. while in the warm tank the extremes were 15° and 12° C.

It is planned to continue the experiment in 1936.

PHYSICAL OCEANOGRAPHY OF THE WATERS ON THE CONTINENTAL SHELF, CAPE COD TO CHESAPEAKE BAY

HENRY B. BIGELOW AND MARY SEARS

The report on Salinity was finished and published in Papers in Physical Oceanography and Meteorology, Vol. 4, No. 1.

ZOÖPLANKTON STUDIES

HENRY B. BIGELOW AND MARY SEARS

1. Studies of the waters of the continental shelf, Cape Cod to Chesapeake Bay. Zoöplankton.

The quantitative measurements and identifications of all the catches were completed.

2. Study of the Siphonophores collected on the "Thor" Expedition, 1908–1910, to the Mediterranean, and the final report almost completed.

3. Study of the Siphonophores collected on the cruise of the "Dana" around the world, 1928–1930.

Two Danish assistants, in Copenhagen, have continued sorting the Siphonophores from the plankton catches during the present year and two large shipments have arrived in this country for further study.

CHEMISTRY OF SEA WATER

K. BUCH, P. H. MITCHELL, NORRIS W. RAKESTRAW

Progress has been made during the last season by the chemical division of the Institution in the following directions:

1. Investigations on the occurrence of free, inorganic iron in sea water, which have been going on during the last three seasons, were finished, and a paper embodying these results has been published.

2. A short paper on the occurrence of boron in North Atlantic waters has also been published.

3. Work on the distribution and significance of nitrite in sea water was continued this season and a paper on this subject is now being prepared.

4. The main features of a new and more convenient method for the determination of dissolved gaseous nitrogen have been worked out, with the help of Mr. Emmel, and after a few minor points have been perfected, the method will soon be ready to apply.

5. Professor Kurt Buch, of Åbo Academy, Finland, carried out a study of the carbonic acid—carbonic dioxide equilibrium in Atlantic water, employing methods which he has used with success elsewhere. Determinations of temperature, salinity, alkalinity, oxygen and carbon dioxide tension were made on surface samples obtained from one cruise of "Atlantis," and also during the crossing to and from Denmark. The carbon dioxide content of the atmosphere was determined simultaneously, and the results, which will be published during 1936, should extend our knowledge of the conditions of exchange of CO_2 between the atmosphere and the ocean. In connection with this same study, a few determinations were made during the summer of the carbon dioxide content in masses of air of different origin. Also, during one cruise of "Atlantis" samples of air were taken at different heights, which showed a decided CO_2 gradient.

6. Dr. Mitchell, with Mr. Maynard, studied the behavior of certain pH indicators in sea water. Simultaneous measurements with the glass electrode and bicolorimeter established the dissociation curves in water of varying salinity for the indicators phenol red and

cresol red at 20° and 25° C. These results confirmed and extended previous observations and should make possible an improvement in the precision of future measurements of the pH of sea water. Dr. Buch coöperated in this study by making simultaneous pH determinations by other colorimetric methods, which led to a redetermination of the salt-error curve for cresol red. The results of all this work have given us a clearer understanding of both the opportunities and limitations of pH measurements in sea water.

7. Additional water samples from between Labrador and Greenland were obtained for the determination of dissolved helium and neon, in the effort to explain peculiar results reported in a preliminary study by Dr. W. D. Urry. These samples are being analyzed at the Massachusetts Institute of Technology.

PHYSIOLOGY OF COPEPODS, SEASONAL DISTRIBUTION OF PLANKTON, AND PENETRATION OF LIGHT INTO THE SEA

GEORGE L. CLARKE

1. The investigation of the feeding of the copepod, *Calanus finmarchicus* was continued as a step in a general analysis of the factors controlling plankton production. A technique was developed for rendering the copepod cultures practically sterile thus making possible critical experiments on the rôle of bacteria in the nutrition of these animals. (In collaboration with Dr. John Fuller and assisted by Mr. Sidney Cobb.)

2. In June a survey was begun of the distribution of the plankton in the Woods Hole region and its changes in relation to the tides and the season. The major part of the work was carried on at a station 7 miles off No Man's Land where a sustained population of *Calanus* was found to exist. Observations were continued at this station, at monthly intervals, throughout the remainder of the year to trace the yearly cycle of hydrographic and biological events, at a point which is as far removed from land influences as possible and still accessible from Woods Hole. Besides collections with net and with pump for the larger and smaller elements of the zoöplankton respectively, and measurements of temperature and light penetration, water samples were taken for analysis of phytoplankton and bacteria and for determination of phosphates, nitrates, and total salinity. (Assisted by Mr. Donald Zinn.)

3. Data was compiled for the calculation of the maximum depth at which vision is possible for fish in various parts of the sea. The

results indicate that during hours of bright sun at the surface fish can see at the bottom in in-shore waters and on the continental shelf.

4. An illustrated account of the work of the Institution was prepared and published by the American Museum of Natural History in their magazine *Natural History*.

5. Measurements were undertaken to ascertain the cause of the large "surface losses" which have been found in the investigation of submarine illumination and to determine the influence of different conditions of sky and sea on the magnitude of such losses. The light moving upward from the surface of the water was investigated by securing photoelectric photometers in an inverted position at the top of a floating tower. A new sea photometer and a new deck photometer were constructed using the Westinghouse Photox Cell and a highly damped micro-ammeter. These instruments were carefully tested and standardized and found satisfactory for the measurement not only of reflection but also of the illumination beneath the surface. The light reflected from the surface, plus the light which enters the water but escapes out again through the surface, represents that fraction of the light fall on the ocean which does not contribute to its supply of energy. The greater part of the "surface loss" was found to be accounted for by a stratum of relatively opaque water extending to a depth of about one meter and caused by bubbles in this stratum, the abundance of which is proportional to the roughness of the sea surface. (In collaboration with Dr. W. M. Powell.)

ZOÖPLANKTON OF THE GULF OF MAINE AND NARRAGANSETT BAY

CHARLES J. FISH

Preparation of a report on the biology of the zoöplankton population of the Gulf of Maine and Bay of Fundy has been continued during the past year, and individual papers on *Calanus finmarchicus* and *Pseudocalanus minutus*, with special reference to production and dispersal, have been completed and are now in print.

In October, a two year program of field investigations was started in Narragansett Bay, the objective being a continuation of similar studies of the biology of the zoöplankton population in the region south of Cape Cod.

NUTRITION OF CALANUS FINMARCHICUS

JOHN L. FULLER

In conjunction with Dr. Clarke the study of the nutrition of the copepod, *Calanus finmarchicus*, was continued. Experiments were designed to test the possibility that bacteria might be an important source of food under natural conditions. Since in the laboratory bacteria alone, even in high concentration, did not support growth of *Calanus*, it was concluded that they must be negligible as a food source in the sea where they are distributed sparsely. The observations of Clarke and Gellis in 1934, that *Calanus* thrives in sea water from which diatoms and other large plankton have been removed by filtration through paper, was confirmed. *Calanus* grew more rapidly however, in untreated sea water than in paper filtered water. This means that certain elements of the nannoplankton, probably naked flagellates, can support the growth of *Calanus*. Since flagellates were less abundant in filtered than in unfiltered water, the relative importance of diatoms and flagellates cannot be determined from these experiments.

Preliminary measurements on the rate of filtration of sea water by *Calanus* suggested that diatoms were too sparsely distributed in the sea to provide all the food necessary for an individual copepod. If these measurements are substantiated, the importance of the nannoplankton as a food for *Calanus* in nature will be established.

PHYSICAL OCEANOGRAPHY OF THE WESTERN NORTH ATLANTIC

COLUMBUS ISELIN

During the past year the "Atlantis" occupied only 183 hydrographic stations. Thus the work of correcting the routine observations has been considerably less than in previous years. Moreover, on the two occasions when the ship made extended surveys, Mr. Woodcock determined the salinity values on board so that there has been no difficulty in keeping the corrected observations up to date.

During the summer months Mr. S. Edward Roos, who acted as oceanographer on the Byrd Antarctic Expedition II, prepared a report on his sonic sounding material, chiefly from the Ross Sea. About 2700 soundings have been corrected and a report is now in the process of being published.

The "Atlantis" temperature and salinity data from the western North Atlantic have been studied further and the manuscript of a general report has been revised as our ideas concerning oceanic circulation have developed. A course in dynamic oceanography is again being given at the Massachusetts Institute of Technology and a considerable amount of time during the past autumn has been devoted to the preparation of the lectures.

INVESTIGATIONS OF BATHYPELAGIC ZOÖPLANKTON AND EXPERIMENTS WITH CLOSING NETS

BENJAMIN B. LEAVITT

Investigations of the quantity of animals living at different depths in the sea have been continued. Two trips were made on "Atlantis" during the past summer and much more data have been gathered by the use of two-meter closing nets. Several stations were completed during the summer and information has been obtained on the amount of plankton collected at definite levels down to a depth of thirty-two hundred meters. Closing devices for two-meter nets have been been improved and found serviceable. In order to gather information on how much water actually passed through the nets while they were being towed, current meters have been devised to measure the passage of water through the mouths of the nets. These were used on a trip on "Atlantis" late in the summer and are still in an experimental stage. The quantities of animals collected at different depths at nine stations have been measured and the Euphausiids contained therein have been identified. The different species have been correlated with the depths at which they live. The fish collected have been sent to Professor A. E. Parr, who has generously offered to identify them.

QUANTITATIVE AND QUALITATIVE STUDY OF THE PHYTOPLANKTON OF BUZZARDS BAY AND VINEYARD SOUND

LOIS C. LILLICK

During the past summer a qualitative and quantitative survey of the phytoplankton of Buzzards Bay and Vineyard Sound was begun in relation to certain physical and chemical factors. Two stations in the Bay and three in the Sound were investigated. Biweekly samples were taken at surface, median, and bottom depths from the first of July to the first of September. Qualitative and quantitative determinations of samples taken from two of the stations in the Sound have been completed through the middle of August.

A check-list of the marine diatoms known and recorded from the western Atlantic between the northern part of West Greenland to the southern part of Central America is being compiled in connection with this survey.

COLOR CHANGES OF FISHES

G. H. PARKER

Work was continued on the color changes of the spiny dogfish, *Squalus acanthias*. This dogfish is dark in color and maintains this condition through pituitary neurohumors carried in its blood. It gives very little evidence of a pale phase and in this respect it is very unlike the smooth dogfish, *Mustelus canis*. There is no reason to believe that nerves play any significant part in inducing a blanching of the spiny dogfish's skin as they do for that of the smooth dogfish. These results are already in process of publication in the Proceedings of the National Academy of Sciences.

Work, begun last year, on the lipohumor concerned with the pale phase of the smooth dogfish, was also continued. Extracts of the skins of some 200 smooth dogfishes were made and studied biologically and chemically. The resistance to heat of the contained neurohumor was demonstrated as well as its solubility in oil, ether, etc. A report is in preparation for publication.

INVESTIGATIONS IN COÖPERATION WITH THE BINGHAM OCEANOGRAPHIC FOUNDATION OF YALE UNIVERSITY

A. E. PARR

The various coöperative projects mentioned in the previous reports were continued also through the year 1935.

In the hydrographic study of the Central American Seas the observations gathered by the "Atlantis" in the Caribbean region, south of the Yucatan Channel, during 1933 and 1934 were subjected to further analysis in the Bingham Oceanographic Laboratory and the first section of the report on the results of this investigation, dealing with the Temperature-Salinity correlations and the horizontal distributions of the various types of water found to occur within the Caribbean area is now almost ready for publication. The greatest part of the calculations, tabulations and drawings necessary for the preparation of the second part of the same report were also completed during 1935. During February to April, 1935, the "Atlantis" made 106 stations in the Gulf of Mexico to obtain further information concerning a peculiar hydrographic instability in the middle layers in this region, first discovered by the Yale Oceanographic Expedition in 1932. As in 1932, a change was again found to have occurred between the early and the later part of the cruise in 1935.

In regard to the distribution of surface salinities, the observations for the two separate years show some very interesting and important differences in detail, while agreeing in the essential feature of a prevalence of very high surface salinities in the interior of the Gulf proper as compared with the surface salinities of the Caribbean region. The data collected in 1935 are now also in the process of preparation for publication in the Bingham Oceanographic Laboratory.

The collecting of records and samples of the floating Sargassum weeds was continued during the 1935 cruise, and served to disclose a surprising degree of variation from year to year both in total quantity and in the ratio of abundance of the two dominant species. Experiments were also made to prove the validity of the collecting method employed by showing that the occurrence of the weeds under normal conditions is strictly limited to the very surface alone, in so far as quantitatively significant amounts are concerned. M. D. Burkenroad continued his studies of the animal life associated with the floating weeds, and is now preparing for publication an account of the general ecological principles governing the life of the epizoan community, and of such specific biological details as have already been established through his work. A report, mainly on the quantitative results of the study of the weeds themselves, is also being prepared for simultaneous publication by A. E. Parr, while further work along biological and taxonomic lines is already in progress or in contemplation as part of the future program.

During the visit to the Gulf of Mexico, bottom trawlings were attempted along the slope of the continental shelf in the north. Although bad bottom conditions caused great damage to the trawls, the results nevertheless give clear evidence of an astounding abundance of bottom life below the region in which the Mississippi outflow meets the offshore waters of the Gulf at the surface. It is the intention to pursue the study of this phenomenon further on the next coöperative cruise of the "Atlantis" to these waters, tentatively planned for 1937.

Taxonomic investigations of deep-sea fishes and various invertebrate groups collected by the "Atlantis" were continued through 1935.

BIOLOGY OF THE GULF OF MAINE

ALFRED C. REDFIELD

The analysis of data obtained during the survey of the waters of the Gulf of Maine in June, 1933 and September, 1934 had indicated that the abundance of zoöplankton occurring at various times and places may be explained by the peculiarities of the non-tidal drift of the superficial waters of the Gulf. The distribution of certain plankton-feeders such as petrels and mackerel, as well as the chief sites of phytoplankton activity, are also related to the circulation system. It has consequently been possible to develop a general theory based on hydrographic data to account for important aspects of the ecological situation presented by the Gulf as a whole.

The importance of vertical mixing in establishing the conditions for physiological activity in the Gulf is under investigation and it has been possible to estimate tentatively the rate at which oxygen is supplied to the deeper water by this process.

Mr. Bostwick Ketchum is conducting an investigation of the rôle of phosphate and nitrate in ecological concentrations in controlling the growth and metabolism of diatoms.

DYNAMIC OCEANOGRAPHY

C. G. ROSSBY

The theoretical investigation of the dynamics of ocean currents reached a certain degree of completion with the publication of a report in which the characteristics of the wind-produced surface layer of homogeneous water was discussed. A computation was then made by Mr. R. B. Montgomery of the wind-produced convergence of surface water in different parts of the North Atlantic. An analysis of vertical wind and vapor pressure gradients in the immediate vicinity of the sea surface seem to indicate the existence of a thin laminary boundary layer next to the water, at least for low wind velocities. The presence of this laminar layer will reduce very markedly the shearing stress between air and water and therefore necessitate a recomputation of the convergence.

We have begun to investigate the effect of large scale horizontal turbulence in producing lateral shearing stresses acting on vertical planes parallel to the direction of the mean motion. These stresses should reveal themselves through the existence of certain preferred velocity profiles cross-stream. With this in mind we are now studying velocity profiles in various sections through the Gulf Stream. Theoretically the investigation is of great interest since it deals with turbulent flow in a rotating system and thus may shed some light on the relative merits of the "momentum transfer" and "vorticity transfer" theories.

DISTRIBUTION OF PHOSPHATES AND OXYGEN IN THE WESTERN NORTH ATLANTIC AND CARIBBEAN SEA

H. R. SEIWELL

A descriptive discussion of phosphate distribution in the western Atlantic was published as contribution No. 64 and two other papers on new methods for calculating the production of organic matter in the open ocean as contributions No. 24 and 77. In this work I was assisted during the year by Gladys Eddy Seiwell who performed the laboratory experiments needed to supplement the field observations and also acted as general assistant.

Our investigation of the mechanism controlling the circulation of phosphorus, oxygen, and other dissolved substances of biological importance in the sea has led to a study of the agencies which bring about vertical exchange of dissolved substances between strata in the deeper parts of the ocean basins. The problem is now being investigated from both field and experimental viewpoints.

In the late summer, during a cuirse on "Atlantis" to the Labrador Basin, we obtained phosphorus, oxygen, salinity, and temperature data for 16 deep stations thus enabling us to extend ten degrees northward the picture of oxygen and phosphorus distribution in the western Atlantic and to test certain theoretical ideas advanced in contributions No. 32 and 64 in more northern latitudes than had heretofore been possible.

The oxygen data from "Atlantis" cruises to the Caribbean Sea and Gulf of Mexico in 1932, 1933, and 1934 have been turned over to me for analysis. With the assistance of Mr. Allyn White, a detailed bathymetric chart of the Caribbean Sea is now prepared and all the data have been reduced and corrected and the sections drawn preparatory to study.

During the year I have also coöperated with Professor C.-G. Rossby on certain problems of physical oceanography.

PHYSICAL OCEANOGRAPHY OF DAVIS STRAIT, LABRADOR SEA AND NEWFOUNDLAND BANKS

EDWARD H. SMITH

The past year has been devoted to a study of the distribution of temperature and salinity in the waters around the Grand Banks and northward between Labrador and Greenland to the southern part of Baffin Bay.

The report as described in last year's report is expected to be ready for publication sometime during the spring of 1936 as Part 2 of U. S. Coast Guard Bulletin No. 19.

PHYSICAL OCEANOGRAPHY OF THE GRAND BANKS REGION AND LABRADOR SEA

FLOYD M. SOULE

Work was continued on the report on the physical oceanography of Baffin Bay, Davis Strait and the Labrador Sea in collaboration with Edw. H. Smith and Olav Mosby until March, 1935. The months of April, May and June were spent on the oceanographic vessel of the International Ice Patrol, the U.S.C.G. Patrol Boat "General Greene," in the region of the Grand Banks, supplying dynamic topographic charts of the region to the Ice Patrol cutters "Mendota" and "Pontchartrain." During this period three current surveys of the critical area were made with reference to the 1000 decibar surface although the temperature and salinity measurements extended in many cases to 1400 meters where the depth of water permitted. In this work 167 oceanographic stations were occupied. An additional 110 oceanographic stations were occupied on an intensive post-season cruise in the region of the Labrador Deep and the supposed location of the Newfoundland Ridge hypothesized by Wüst. The measurements on the post-season cruise took place between July 10 and August 23, all stations being occupied from the surface to as near bottom as was practicable. At 12 stations, selected to form a section from Cape Farewell southwestward to deep water and thence south-southeastward to a point south of the supposed Newfoundland Ridge, a total of 95 samples were taken for oxygen determinations and an equal number of helium samples were taken.

On the post-season cruise 2036 sonic soundings were taken with the Fathometer. These have been corrected, tabulated, and transmitted to the Hydrographic Office and to the International Hydrographic Bureau. An additional 1355 corrected soundings taken on the "Marion" Expedition in 1928 were tabulated and forwarded to the same offices. A bathymetric chart of the Labrador Sea based on all available soundings has been constructed.

Since the return of the "General Greene" to the United States on September 5 the oceanographic section of the U. S. Coast Guard Bulletin No. 25, dealing with the 1935 season's work, has been prepared for publication and the work of collaboration on the report on the physical oceanography of Baffin Bay, Davis Strait and the Labrador Sea has been resumed.

INVESTIGATIONS ON MARINE FUNGI

F. K. SPARROW, JR.

Experiments were made on cultivation, in an artificial medium, of *Sirolpidium bryopsidis* an endophytic marine fungus, found in nature as a facultative saprophyte of the green alga *Bryopsis plumosa*.

After trying a number of different media, it was found that 0.5% and 1.0% solutions of dextrose in filtered sea water had a markedly stimulating effect on the production of extra-matrical growth.

STUDIES IN SEDIMENTATION AND ON THE GEOLOGY OF SUBMARINE CANYONS

H. C. STETSON, J. L. HOUGH, MARSHALL SCHALK

The work begun in the summer of 1934 on the submarine canyons of Georges Bank was continued in the outer part of the Hudson Gorge and in three canyons further south off the Delaware-Maryland coast. In 13 successful tows material was dredged from the walls of these valleys, very different in lithology, mechanical composition, degree of consolidation and fauna from the product of present day sedimentation. It is possible that these samples came from the truncated outcrops of strata forming the canyon walls. However, because the contained foraminifera are Recent forms which cannot range farther back than Pleistocene, the implications involved are too far-reaching to warrant a full acceptance of the evidence at this time. A detailed report is in progress.

We were accompanied on this cruise by Dr. Charles J. Piggot of the Geophysical Laboratory of the Carnegie Institution who tried out for the first time in deep water a new type of coring tube. With this tube, operated by explosives, cores were obtained, some of which are among the longest ever taken.

A paper in three parts, with J. A. Cushman and L. W. Stephenson, on the results of the work on the Georges Bank canyons, was completed and is now in the hands of the Geological Society of America awaiting publication.

A report is in preparation on the cores taken last January on "Atlantis" in the fine grained calcareous sediments that mantle the volcanic cone of Bermuda.

Mr. Edward Roos of the 2d Byrd Antarctic Expedition very kindly donated several cores which he obtained on the "Bear" in the Ross Sea. They are of especial interest as they represent deposition directly from the front of a large continental ice sheet. Mechanical and mineralogical analyses are at present being carried out.

In October a program of seismological work was carried out on "Atlantis" by Dr. Maurice Ewing under the general direction of Professor Richard M. Field. A profile was run from Cape Henry to the break in slope for the purpose of ascertaining the thickness of the Coastal Plain wedge. The ordinary seismic instruments used in oil prospecting were employed, with the geophones adapted for use under water. Four successful stations, with several shots at each, were made and report is in progress.

During the summer of 1935, J. L. Hough took samples of the bottom deposits and beach sands of Cape Cod Bay. The study was extended to the region north of the tip of Cape Cod, and includes the southern portion of Stellwagen Bank. Mechanical analyses of the samples have been made, and the work of correlating between the characters of the sediments and the environment is in progress. Further studies of the material, involving measurement of roundness of grains and identification of minerals, are planned.

EFFECT OF EPINEPHRINE ON RATE OF WATER EXCRETION IN THE TOADFISH

L. A. TOTH

The effect of injections of epinephrine on the water excretion in mammals and in the frog has been extensively studied by various investigators. Their results indicate that either a polyuria or an oliguria can be brought about after such injections, depending on the conditions of the experiment. To determine whether or not the same results could be obtained in aglomerular kidneys, in which the circulatory system is much different from that of the mammalian or amphibian kidney experiments were made on the toadfish (*Opsanus tau*), under ethyl urethane anesthesia. The rate of water excretion was studied by annulating one of the ureters and observing the movement of the meniscus in the urine column. Sixteen injections of 0.2, 0.05, and 0.02 mgm. of epinephrine hydrochloride in one cubic centimeter of 25 per cent sea water occasionally resulted in a small and transitory increase in the rate of water excretion. Control experiments in which only sea water was injected seemed to indicate that this transitory increase was due to the added fluid.

To extend the investigation of circulatory factors in urine production, studies of the effect of anoxemia, and of the occlusion of the dorsal aorta, were also begun. The anoxemia was produced by bubbling nitrogen through the water near the gills of a fish in a closed vessel.

INFLUENCE OF CHANGING TEMPERATURES ON THE BEHAVIOR OF SCUP (*STENOTOMUS CHRYSOPS*)

MORGAN UPTON

The behavior of Mackerel when the temperature of the water in which the fish are swimming is lowered was studied during the summer of 1934 with the hope that information regarding the causes of the fall migration of the fish would be obtained (cf. Report of Woods Hole Ocean. Inst., June, 1935).

Since Scup are known to migrate to definite offshore regions in the late fall, an investigation of the behavior of this fish was carried out under conditions analogous to those which obtained in the experiment with the Mackerel.

The fish were placed in a tank containing 40 gallons of fresh sea water which was cooled by a motor driven refrigerating unit. Fresh sea water was circulated continuously through the tank while the water was being cooled, and a siphon system kept the water at a constant level. The temperature of the sea water at the beginning of each experimental run was approximately 20° C. and about twelve hours were required to lower the temperature of the water to 6° C.

Four sets of observations involving four groups of six fish each were made. As the temperature of the water fell the general activity decreased. At 14° C. all the fish still were normally oriented and swimming slowly but responded only slightly when poked with a glass rod. At 8.5° C. swimming movements were interrupted by periods of quiescence during which the fish turned bottom up and settled slowly to the bottom. At 7.5° C. several of the fish were completely immobile, displaying no response to poking with a glass rod. At this temperature two of the immobile fish from each group were placed in a small tank and gradually warmed by circulating fresh sea water (temperature 20° C.) into the tank. All of the fish which were so treated recovered full vigor and lived for several weeks in one of the large laboratory storage tanks.

Between 7° C. and 6° C. all the fish were immobilized and none of them recovered on being warmed if the temperature of the water had gone below 7° C. This seems to be a lethal temperature for Scup under these conditions.

It was thought that the relatively rapid cooling might have killed the fish, because of some shock effect. To test this, twenty-eight Scup (5 to 12 inches in length) were placed in a large concrete laboratory storage tank to be cooled by the normal temperature change brought about by the onset of winter.

The behavior of the fish under the effect of slow cooling was not greatly different from that of those which were cooled rapidly. All the fish in this group were fairly vigorous and ate regularly, until the temperature of the water was lowered to 7° C.

Below this temperature the eating ceased and all the fish died in a period of ten days during which the temperature fell from 7° C. to 4° C.

STUDIES IN MARINE BACTERIOLOGY

SELMAN A. WAKSMAN, C. E. RENN, MARGARET HOTCHKISS,
W. BURROWS, F. H. JOHNSON, ASSISTED BY T. CORDON

During 1935, the investigations in Marine Bacteriology were grouped around the following problems: 1) transformation of organic matter in sea water; 2) abundance of bacteria in water as determined by plate, microscopic, and attachment slide methods; 3) fixation of nitrogen by marine bacteria; 4) respiration and utilization of different carbohydrates by marine bacteria; 5) oxidation-reduction potentials of sea water, as modified by bacterial activities; and 6) the nature of the causative agent of the eel-grass disease.

It was calculated that under laboratory conditions, using oxygen consumption as the index, that about half of the dissolved organic matter of sea water may be decomposed by bacterial action, about 60% of this being completely oxidized and 40% converted to bacterial cell substance. Temperature, concentration of available organic matter and inorganic nutrients, especially nitrogen and phosphorus, and the position of the water mass involved are factors influencing the rate of extent of decomposition.

In the comparative studies of plate, direct, and attachment slide methods of determining numbers of marine bacteria all procedures showed considerable variation, but correlations were always positive—the direct microscopic methods gave from 100 to 1000 times the number counted on plates; the wider ratio in freshly collected water, and the lower in cultures or stored water. Pure cultures gave ratios between direct and plate methods of 1–15:1.

Nitrogen fixing organisms of the Clostridium type were demonstrated in marine mud, surface water, and on algal material, appearing more abundantly in the mud than in the water. Thirteen cultures of this organism, all fixing nitrogen with glucose as a source of energy, were investigated. The Azotobacter type has been demonstrated in the sea only occasionally (M. Hotchkiss).

The cultural characteristics of 50 pure strains of marine bacteria isolated at random from sea water and bottom material were studied. Marked differences in their ability to ferment ten different carbohydrates were observed. The endogenous oxygen uptake of twenty-five of these cultures was studied under carefully controlled conditions, confirming information secured earlier by other methods in this laboratory. In cultures enriched by glucose appreciable excess in oxygen uptake over the endogenous metabolism was secured only when the concentration of glucose exceeded the equivalent of organic matter in natural sea water. Glucose appeared to be a more readily available source of energy for marine bacteria than did alginic acid, though many bacteria were capable of utilizing the latter (F. H. Johnson).

In the studies on oxidation-reduction potentials in water and muds, it was found that sea water, on standing, showed an initial negative drift followed by a return to original levels, that organic matter retarded this return, and that the behavior was unaffected by light. Potential measurements of initial reactions in the Gulf of Maine indicated increasing negativity with depth and potentials of bottom materials approximated those of surface water (W. Burrows).

Inoculation experiments were performed with the unidentified *Labyrinthula* previously isolated from diseased eel-grass. These tests demonstrated the specific parasitic nature of the protozoan and indicated its rôle as the immediate cause of the *Zostera* disease (C. E. Renn).

WATER MOVEMENTS IN THE GULF OF MAINE

E. E. WATSON

A paper on mixing and residual currents in tidal waters, based largely on observations from the Bay of Fundy, has been completed and sent to press.

A series of temperature and salinity measurements were taken every two hours at an anchor station in the Gulf of Maine. The calculated dynamic heights of the surface at this one station in September showed a maximum variation of 4.4 cm. which is about half the variation shown by Bigelow over the major part of the Gulf. This means that dynamic contours constructed from single series of observations at each station may be misleading unless the contour interval is several cms. At least dynamic contours should not be used for current charts in a region until it is known how large the variation in dynamic height at any one station during a tidal period may be, and also whether the theoretical condition of no bottom current is even approximately true.

With the assistance of Madeleine Watson the observations on nearly all of the Gulf of Maine cruises from June, 1933, to September, 1934, have been plotted on graphs, including many T-S diagrams, and the corrected densities calculated for use in dynamic computations.

Calculations made for the velocities and transport across sections from Nova Scotia to Georges Bank and from Georges Bank to Nantucket Shoals indicate that serious errors are introduced by the theoretical assumption of no bottom current, but when sections completely bounding the Gulf are available the assumption may be partly corrected by considerations of continuity. There appears to be an increasing demand for direct current measurements, especially near the bottom, to furnish absolute values as a basis for the relative values which can be obtained from the dynamic heights.

MODIFICATIONS OF THE EYES AND OF VISION IN DEEP-WATER CRUSTACEANS

JOHN H. WELSH

As a first step in a program of study of the structure and function of the eyes of deep-water crustaceans two trips were made on "Atlantis" during which collections of crustaceans were taken at known depths down to 3200 meters. Modification with depth, hence with light intensity, of the eyes of these forms is now being studied with the coöperation of F. A. Chace, Jr. Particular attention is being paid to the relative size of the eyes, the degree of pigmentation, and the development of the rhabdomes or image receptors.

Attempts to keep certain of the acanthephyrids alive for a sufficient length of time to make possible observations on their reactions to light, and future studies of their visual acuity were successful. At low temperatures they were maintained in apparently normal condition for at least three days.

During the time not occupied by the trips at sea, an investigation of the internal control of pigmentary changes in the eyes of shallow water crustaceans was continued. Lobsters were kept in constant darkness for 58 days and at the end of this period daily movements of pigment within the eye were still occurring as they do under normal conditions. This indicates the presence of an internal cyclical mechanism which continues to operate under constant conditions. These findings have some general significance as diurnal changes in degree of activity are widespread among marine organisms and it is now evident that they may not be entirely due to daily changes in the external environment.

STUDIES OF COPEPODS

C. B. WILSON

During the present summer copepods were identified from plankton taken during the Johnson-Smithsonian Expedition to the Porto Rican Deep. I have also worked upon a collection of sand and mud dwelling copepods obtained around Mt. Desert Island on the Maine coast. This includes many new genera and species which have been carefully described and figured, ready for future publication.

In August I received the plankton collected during Admiral Byrd's last trip to the Antarctic and have made a preliminary examination of a portion of it, in preparation for more complete identification and future report.

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